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ORIGINAL ARTICLES.

I.—Some Coal-Measure Crustaceans with Modern Representatives.

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AMONG the numerous fossils obtained by Dr. L. Moysey from the clay-ironstone nodules of the Coal-measures near Ilkeston, Derbyshire,[1] is one referred to by its discoverer as "a shrimp-like animal," in a recent note published by him in the Geological Magazine for May last.[2] Dr. Moysey was so fortunate as to secure several well-preserved examples of this very interesting Schizopod Crustacean from a disused brickfield on the Shipley Hall Estate, owned by E. M. Mundy, Esq. These he most liberally placed in my hands to examine and describe. Dr. Moysey also commended me to the Rev. C. Hinscliff, M.A., of Craig Royston, Bickley, Kent, who had in his possession another specimen of this crustacean obtained from the same locality. Mr. Hinscliff not only sent me his fossil to study, but generously presented it to the Geological Department of the British Museum (Natural History Branch), Cromwell Road, where it will be preserved and exhibited.

Præanaspides præcursor, H. Woodw., gen. et sp. nov.

Description of the fossil.—One of the largest and most perfect of these Schizopod-like Crustaceans measures 57 mm. in length (see Fig. 1). A second specimen is 30 mm. in length. A third, showing the dorsal aspect, is 40 mm. long (Fig. 2). Mr. Hinscliff's specimen (Fig. 3) is 30 mm. in length, but the head is imperfectly preserved. A nearly complete small individual is 15 mm. long; it is associated with a fifth, but less perfect, example measuring only 10 mm. in length. The two last-named are exposed on the split surface of a nodule, lying one on either side of a Calamite stem.

The head is extremely small, being only 6 mm. long, or equal in length to the two anterior thoracic segments; the rostral portion is slightly produced and bent a little downwards; the inferior margin

[1] "Two New Species of *Eurypterus* from the Coal-Measures, Derbyshire," by H. Woodward: Geol. Mag., 1907, pp. 277–82, Pl. XIII.

[2] "On a Method of Splitting Ironstone Nodules by Freezing them," by L. Moysey: Geol. Mag., 1908, pp. 220–2.

is shorter than the dorsal and slightly emarginated behind the base of the antennæ. About one-fifth of the head is strongly marked off behind by the cervical furrow or groove which runs parallel to its posterior border, or it may represent the union of the first thoracic segment coalesced with the cephalon.

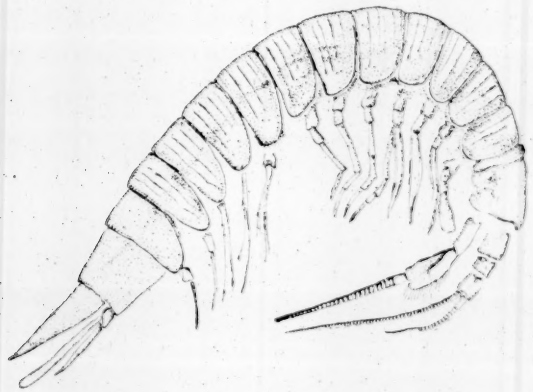

Fig. 1.—*Præanaspides præcursor*, H. Woodw., gen. et sp. nov. (Clay-ironstone. Coal-measures: Ilkeston, Derbyshire. From Dr. L. Moysey's collection. About twice nat. size.

Eyes.—The presence of a pedunculated eye seems indicated—though not very clearly—by a small rounded hollow at the base of the antennule.

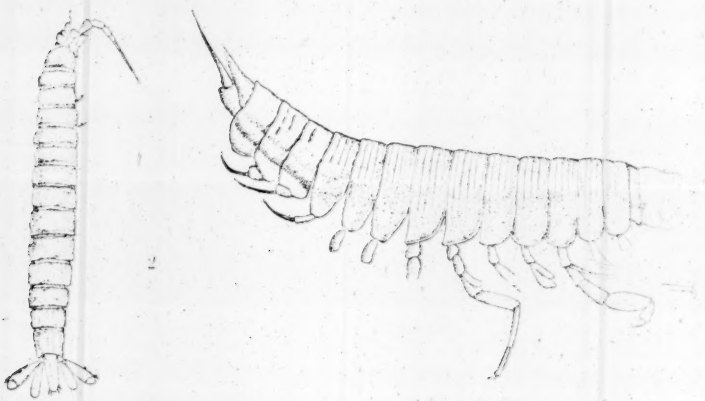

Fig. 2.—*Præanaspides præcursor*, H. Woodw.; dorsal aspect. Coal-measures: Ilkeston, Derbyshire. Enlarged one-fifth nat. size.

Fig. 3.—*Præanaspides præcursor*, H. Woodw., gen. et sp. nov. Coal-measures: Ilkeston, Derbyshire. Collected by Rev. C. Hinscliff, M.A., and presented by him to the Geological Department of the British Museum (Natural History). × 2½ nat. size.

Antennules.—These have three stout basal joints, measuring together 5 mm. in length, of which the first is the broadest, the second is very short, while the third, or distal one, is the longest; each bears a pair of multi-articulate flagella, the outer one being 10 mm. in length, and the inner and smaller one is only 5 mm. long.

Antennæ.—The antennæ are more robust than the antennules; the three basal joints together are 7 mm. in length, and the third joint bears a large oblong spatulate scale, or exopodite, fringed with setæ. The single flagellum is fully 8 mm. in length.

Mandibles and maxillæ.—The mandibles and maxillæ cannot be seen in the fossil; if preserved, they are hidden from view by matrix.

Post-cephalic segments.—Assuming that the first thoracic segment is coalesced with the head, there are seven free thoracic segments behind the head, the three most anterior of which are each about 3 mm. long and 3 mm. deep; those which follow gradually increase to 4 mm. in length and 5 mm. in depth. The lateral margins of the anterior segments are broadly rounded, while the five abdominal ones which succeed them gradually increase in depth and become more pointed and slightly falcate posteriorly.

Appendages.—The first free (= to the second) thoracic segment carries a pair of legs or maxillipeds (endopodites), the three first joints of which are short, followed by a larger one (the *meros*), which is about equal to the three proximal joints in length, and is broadest at its distal end; two smaller joints and a claw follow. Apparently there was no exopodite developed on this limb, or, if present, it may have been rudimentary, but it cannot be detected. Each of the four segments which follow carries a pair of appendages about 10 mm. in length, having a short, broad coxal joint, followed by a basipodite, which supports on a slender joint or branch a multi-articulate setose exopodite, and an endopodite in the form of a seven- or eight-jointed slender leg, of which the carpus appears to be the longest joint, ending in a single claw or nail. The basal joint of each of these four pairs of appendages probably also bore a pair of ovate-oblong branchial lamellæ, but these, being exceedingly delicate structures, are not clearly discernible in the clay-ironstone matrix, but of their actual existence in the fossil I have little doubt.

The two pairs of limbs, borne upon the hindmost (seventh and eighth) thoracic segments, do not appear, like the earlier four which preceded them, to have possessed the multi-articulate setose exopodites, but only the slender limbs (the endopodites), similar in character to those borne by the more anterior segments.

Abdominal series.—The five most anterior segments of the abdomen, as already stated, are deeper and have more pointed lateral margins than the thoracic ones which preceded them. These had each a pair of slender, bifid, many-jointed, setose swimming appendages, borne upon a stronger basal joint, articulated with the antero-lateral border of each of the five segments. The sixth segment is more or less cylindrical in form, being 5 mm. in depth and 5 mm. in length, and slightly narrower posteriorly, somewhat ridged dorsally, and grooved and ridged laterally to give firmer attachment to its appendages; these form, with the 'telson,' the tail-fan or uropods. On the central

line the 'telson' or seventh segment is articulated, which is 7 mm. in length, and, seen in profile, appears to be strongly acuminate, but when viewed dorsally it is found to be 3 mm. broad, narrowing to its rounded distal end, which is armed with spines along its lateral borders, and has three or four larger spines on either side near its extremity. On either side a short basal joint articulates with the segment, giving attachment to two ovate-oblong uropods, thrice as long as they are broad, the outer of which is much the larger, and has a semicircular transverse suture or articulation near its distal extremity, and its lateral outer margin fringed with spines, of which the largest are developed near the extremity; the inner uropod is smooth, narrower, and destitute of spines upon its margin (see Figs. 4 and 5). (The spine-like appearance of the telson and the narrowness of the uropods in Dr. Moysey's and Mr. Hinscliff's specimens (Figs. 1 and 3) is due to these appendages being seen in profile, the broad, flat surfaces being buried in the matrix, and only the edges exposed.)

Each segment of the body is scored by three to four fine vertical parallel lines passing down from the dorsal line to the lateral margin; there is evidence also of a delicate minute articulation between each of the segments on its lateral median line, and a row of extremely minute moniliform ornamentation on the posterior border of the last four or five segments (see Fig. 5).

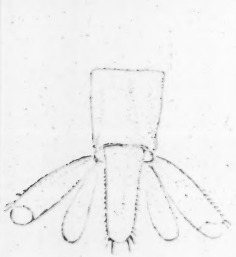

Fig. 4.

Fig. 5.

Fig. 4.—*Præanaspides præcursor*, H. Woodw., showing sixth abdominal segment and telson with the uropods (tail-fan).

Fig. 5.—*Præanaspides præcursor*, H. Woodw., showing eight posterior body segments and telson, with the uropods of the sixth segment forming the tail-fan.

The most striking features in this Coal-measure Crustacean, for which I venture to suggest the name *Præanaspides* (on account of its close affinity to the living genus *Anaspides*[1]), are the extreme smallness of its head, there being no extension backwards of a carapace over the body, only the first thoracic segment being blended with the head, all

[1] Founded in 1894, Trans. Linn. Soc. Zool. (2), vi, 3. A preliminary account, without figures, was published in Proc. Roy. Soc. Tasmania, 1892. "A Memoir on the genus *Anaspides* and its affinities with certain Fossil Crustacea," by W. T. Calman, D.Sc., F.L.S., F.Z.S., appeared in the Trans. Roy. Soc. Edinburgh, vol. xxxviii (1896), pt. iv, No. 23, pp. 787–802, pls. i and ii, 4to, to which we shall refer again later on.

the others being distinct and bearing each its own separate tergum and serial paired appendages; similar to those of the succeeding abdominal somites, the head being no larger than in an Amphipod (which latter it also somewhat resembles in the general form of its body). The eyes are not clearly preserved in the fossil, but they appear to have been borne upon a short penduncle close to the base of the antennules. These antennules were supported upon three stout basal joints, and carried a long outer and a shorter inner flagellum; the antennæ support on their distal joint an elongated, setose, rounded scale and a single stout flagellum. Of the mouth appendages there is no evidence in the fossil, but the second thoracic (the first free segment) no doubt carried a pair of maxillipeds, as they differ in being stouter and broader distally at the fourth or fifth joints than those which follow, and consist only of an endopodite or walking limb (or a simple claw-like organ?). Four at least of the six appendages which follow are true Schizopod limbs, having a well-developed, setose, many-jointed exopodite attached to each leg (the endopodite), and probably also carrying branchial lamellæ on their basal joints.

The two hindmost pairs of thoracic limbs may not have been provided with exopodites. The five abdominal segments following bear true bifid swimming-feet (multi-articulate and setose): the sixth segment is longer and more cylindrical, and bears on each side, upon its distal, lateral extremity, two rounded, scale-like uropods, or swimming organs, resembling the lateral lobes of the tail-fin in the Macroura, and a rounded central telson or terminal joint.

Allied Fossil Genera.[1]

1. *Gampsonyx fimbriatus*, Jord. & v. M.—A form was described under this name by Jordan & von Meyer in 1854[2] from the Coal-measures

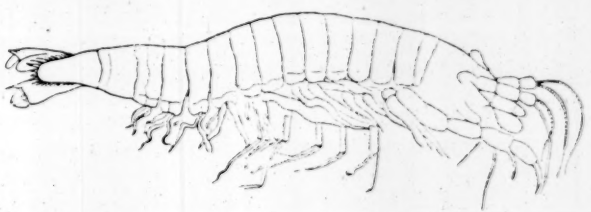

Fig. 6.—*Gampsonyx fimbriatus*, Jordan & v. Meyer. Permo-Carboniferous: Saarbrück, Rhenish Prussia. Drawn from Jordan & v. Meyer's plate in the *Palæontographica*, vol. iv (1856).

[1] The three forms referred to here have been discussed by Dr. Packard and form his groups Syncarida and Gampsonychidæ (American Naturalist, vol. xix (1885), pp. 790–2; Mem. Nat. Acad. Sci., Washington, vol. iii (2), 1886; Proc. Boston Soc. Nat. Hist., vol. xxiv (1889); see also Packard's "Textbook of Zoology," 5th ed., 1886. He here uses the term Syncarida as including *Gampsonyx*, *Acanthotelson*, and *Palæocaris*. Dr. Calman has also figured and noticed them in his memoir on *Anaspides* (see Trans. Roy. Soc. Edinb., 1896, already quoted). The figures of these here given are reproduced from Dr. Packard's restorations.

[2] "Ueber d. Steinkohlenformation von Saarbrücken": *Palæontographica*, vol. iv (1856).

of Saarbrück, which are probably of Permo-Carboniferous age like the Gaskohle of Bohemia.

The eyes in *Gampsonyx* are said to be pedunculated; the bases of the antennules are three-jointed and have two nearly equally long flagella; the antennæ support a large rounded scale, and they have a three-jointed peduncle and a flagellum. The head is short, and the hinder part has a strongly marked division as seen in *Præanaspides*, and may be a distinct eighth segment, but more probably its separation as a distinct segment is a matter of interpretation of the fossil. *Gampsonyx* has a pair of powerful raptorial limbs belonging (Dr. Calman believes) to the first or second thoracic legs. The other thoracic limbs (though obscure) appear to agree nearly with the Schizopod type in having an exopodite and endopodite present in each (although the drawing is not very clear). Dr. Anton Fritsch has described two forms[1] under the genera *Gasocaris* and *Gampsonychus* which may also belong to this group of Palæozoic Crustacea of late Coal-measure age.

2. *Acanthotelson stimpsoni*, Meek & Worthen, 1865 (Fig. 7).—This crustacean was obtained from the Coal-measures of Illinois (Proc. Acad. Nat. Sci., Philadelphia, 1865, p. 41). Two species are described, viz. *A. inæqualis* and *A. stimpsoni*. Packard, who has given a restoration of this genus, considers the head to be composed of two segments, the second being separated by an impressed line from the first; there is not a true articulation between them. (The eyes are unknown.) The antennules have a three-jointed peduncle which carries two flagella[2]; the antennæ have also a three-jointed peduncle and a moderately long flagellum. The seven separate thoracic segments each bears a pair of long, robust, seven-jointed walking-legs, the first and second pairs being the largest, and having their penultimate joints armed with stout spines. No exopodites appear upon the thoracic limbs. *Acanthotelson* has five pairs of well-developed setose swimming-feet upon the abdominal segments. The uropods of the tail-fan are slender in form and bordered by spines or bristles, and so also is the telson (see figures of this genus and of *Palæocaris* in Geol. Mag., 1881, p. 533).

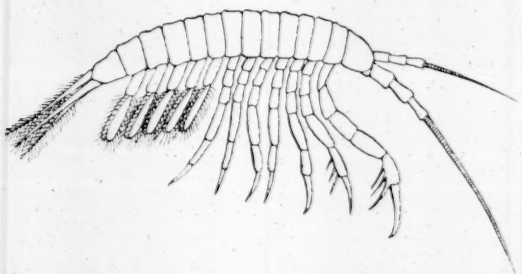

Fig. 7.—*Acanthotelson stimpsoni*, M. & W. Coal-measures: Illinois. Copied from Dr. Packard's figure.

[1] Dr. Anton Fritsch, "Fauna der Gaskohle und der Kalksteine du Permformation Böhmens," Bd. iv (1901), Heft 3.

[2] Packard only represents one flagellum in his figure (see Fig. 7).

Pl. XIV, Fig. 4, and text-fig.; also of *Palæocaris Barnettii*, H. Woodward, sp. nov., p. 533, Pl. XIV, Fig. 3*a*, *b*, Coal-measures, Irwell.

3. *Palæocaris typus*, Meek & Worthen, 1865 (Fig. 8) (Proc. Acad. Nat. Sci., Philad., and Report Geol. Surv., Illinois, 1868), was obtained by its original describers from the Coal-measures of Grundy Co., Illinois. It was afterwards redescribed by Packard in 1866.[1] The head is represented as truncated in front and is quite small; the body uniformly segmented; there are seven distinct thoracic segments, but over these there is no backward extension of the head-shield; the first five abdominal segments have downwardly projecting pleuræ; the sixth segment is elongated and cylindrical in form. The tail-fan and telson are similar to those of the Palæmonidæ, or of a Mysis-like shrimp. The eyes are not seen in the fossil, but the antennules have a stout three-jointed peduncle strongly developed, and each carries a pair of flagella, the outer one longer than the other. The antennæ carry a broad scale, or exopodite, and a long multi-articulate flagellum. The thoracic appendages (as represented in Packard's restoration) have each a three- or four-jointed exopodite borne upon a slender walking- or swimming-limb, the distal extremity of which latter is not shown. Each of the five (abdominal) segments which follow carries a pair of pleopods of the usual slender, setose, multi-articulate form.

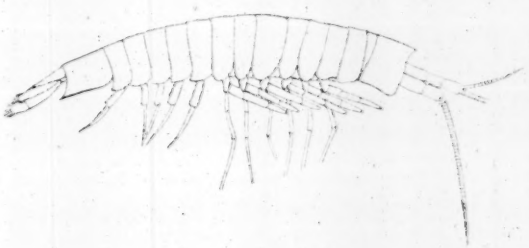

Fig. 8.—*Palæocaris typus*, M. & W. Coal-measures: Illinois. After Dr. Packard's figure.

Living analogues of Coal-Measure Schizopods.—In the examination of fossil forms from the older rocks, we are seldom so fortunate as to find a living analogue by which to interpret these too often rare and imperfect organic remains; nevertheless, amongst the discoveries made in Australasia in recent years, two forms have attracted considerable attention, as indicating very early and primitive types of Crustacea, and throwing an important light on several remarkable Coal-measure Crustaceans, previously without any very near existing representative.

1. The first of these living Schizopod Crustaceans was noticed, under the name of *Anaspides tasmaniæ*, by Mr. G. M. Thomson, of Dunedin, in 1894.[2] Its describer discovered it it in a freshwater pool, at an

[1] Mem. Acad. Nat. Sci., Washington, vol. iii (2), 1886. Abstract in Amer. Naturalist, vol. xix (1885), pp. 700-2.

[2] Trans. Linn. Soc. Lond., Zoology (2), vol. vi (1894), p. 3. A preliminary account, without figures, has been previously published in Proc. Roy. Soc., Tasmania, 1892.

altitude of 4,000 feet, on Mount Wellington in Tasmania.[1] The very striking peculiarities of the animal, the absence of a carapace, the presence of plate-like gills attached to the bases of the thoracic legs, and the possession of an auditory organ in the pedunele of the antennules, led Thomson to regard it as the type of a new family of Schizopods, the Anaspidæ, while suggesting that it might be entitled to even higher specific rank.[2] Fresh specimens of *Anaspides* having come into Dr. Calman's hands, when studying at the Museum of University College, Dundee, he was enabled to add some important points to Mr. Thomson's previously published account of the external anatomy of the animal, and to compare it with some already described fossil forms. This he has done in an admirable memoir communicated to the Royal Society of Edinburgh in 1896,[2] from which we venture to make some extracts.

ANASPIDES TASMANIÆ, G. M. Thomson, 1896.

Dr. Calman points out that Thomson (in his original description) attributes to this Crustacean the possession of eight free thoracic segments, but Calman shows that the first of these is not actually a separate segment, being a part of the head, the supposed division being in reality only a superficial groove in the integument, corresponding no doubt to the "cervical sulcus," which in the Mysidæ crosses the carapace immediately above the mandibles, and he accordingly identifies it with this sulcus. It is also homologous with the cervical groove in the Decapods, behind which the segments bearing the two pairs of maxillæ would morphologically be placed.

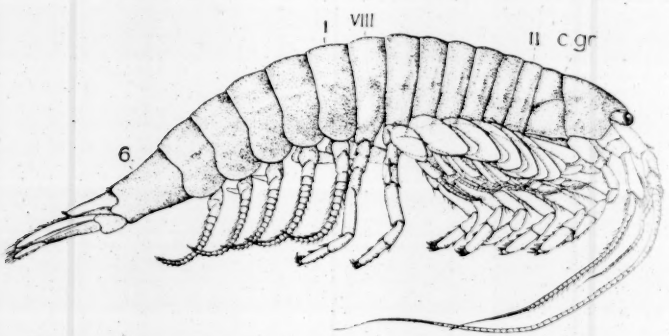

FIG. 9.—*Anaspides tasmaniæ*, G. M. Thomson (living), from freshwater pools 4,000 feet above the sea, on Mount Wellington, Tasmania. c.gr. = cephalic groove; II–VIII, the seven free thoracic segments; 1–6, the six abdominal segments; the seventh is the 'telson' or tail-spine. Drawn from a specimen in the British Museum (Nat. Hist.) under Dr. Calman's direction. (All the figures have been drawn from nature by Miss G. M. Woodward, except Figs. 6, 7, and 8, which were copied by her from Dr. Packard's restorations.)

[1] Mr. G. M. Thomson has since added another locality, namely, "Lake Field," a spot forty miles from Hobart Town, Tasmania, also at an elevation of about 4,000 feet above the sea (Trans. Roy. Soc., 1897, op. cit., p. 802).

[2] Trans. Roy. Soc. Edinb., vol. xxxviii (1897), pt. iv, pp. 787–802. 4to.

From this he infers that in *Anaspides*, in the Mysidæ, and in the Decapods a primary sulcus exists, delimiting an anterior region, or head, to which three pairs of appendages, antennules, antennæ, and mandibles belong[1] (the region of the three-paired appendages of the Nauplius, the "primary head-region" of the Crustacea, according to Claus).

Dr. Calman has observed what appear to be a group of 'ocelli' on the head just in front of the cervical furrow; as no similar larval eyes exist in any known adult Malacostracan, this is indeed a most embryonic character. He is also able to confirm Thomson's discovery of an auditory organ in the base of the antennule of *Anaspides*, a fact of very great interest, such organs having at one time been considered as almost confined to the Decapoda. But the discovery of paired otocysts in the head of certain Amphipoda (*Oxycephalus*), being regarded by Claus as probably homologous to the auditory organs in the Decapods, he thinks they may have been a character of the primitive Malacostraca, a further indication of the more generalized and primitive type presented to us in *Anaspides*.

The compound eyes are pedunculated, and placed at the base of the antennules in an emargination of the head which forms a slight rostral prolongation above the eye-stalk.

The antennules are supported on a stout three-jointed peduncle, of which the first is the longest, while the third joint bears a short inner and a long outer flagellum.

The antennæ, the peduncle of which is composed of two stout basal joints, while a third distal joint bears an elongate-oval, setose scale or exopodite, and also a long multi-articulate flagellum armed with minute spines or bristles. Dr. Calman describes the mandible, the lower lip (labium or prognatha), the first and second maxilla, and then passes to the thoracic limbs,[2] the first pair being maxillipeds, the endopodite developed as a stout seven-jointed leg, bearing on its inner face two flattened setose lobes and two branchial lamellæ on the outer face of its basal joint, and a rudimentary slender exopodite on the second narrow joint (the basipodite), the leg terminating in a single claw.

Each of the four pairs of thoracic legs which follow bears two broad, delicate, oval, branchial lamellæ on the coxal joint, and a well-developed, many-jointed, setose exopodite on the second joint of the endopodite, which forms a strong walking-leg fringed with hairs. Of

[1] In this arrangement the eyes are apparently not admitted as representing a separate segment, although they have been so considered by Milne-Edwards, Bell, Dana, Charles Darwin, Spence-Bate, Sar- & Lang, Huxley, H. Woodward, and others. Charles Darwin writes: "If that part of the larva in front of the mouth bearing the eyes, the prehensile antennæ, and in the earlier stage two pair of antennæ, be formed, as is admitted in all other Crustacea, of three segments, then beyond a doubt, from the absolute correspondence of every part . . . the peduncle of the Lepadidæ is likewise thus formed" (Mon. Cirripedia, Ray Soc., 1851, "The Lepadidæ," p. 25).

[2] In Dr. Calman's figure of *Anaspides* (Fig. 9, *ante*, p. 392) the segments are numbered on the assumption that the first is welded with the head, and the free segments commence with the second thoracic somite, thus the number of the thoracic segments would actually be eight.

the two legs which represent the next succeeding segments the anterior has a smaller branchial lamella on its basal joint and only a rudimentary exopodite, while the posterior pair have neither any branchial lamella nor exopodite developed, but only the walking-leg or endopodite.

The five succeeding (abdominal) segments each bear a pair of setose many-jointed pleopods, and the margins of the segments have their epimera more developed; the sixth segment is tapering, cylindrical in form, and bears upon its median dorsal line a short rounded telson, or seventh terminal joint, fringed with minute spines, and two lateral, much longer oval uropods fringed with hairs forming the tail-fan, the outer exopodite of which has a transverse suture crossing it nearly midway.

2. *Koonunga cursor*, O. A. Sayce, 1907.[1]—The second living analogue of the Coal-measure Schizopods under consideration was discovered by Mr. J. A. Leach, M.Sc., in some small freshwater reedy pools beside a tiny runnel which joins the Mullum Mullum Creek, Ringwood, near Melbourne, Australia. (The name *Koonunga* is derived from the aboriginal name of a creek which runs near where the specimens were collected.)

Koonunga resembles *Anaspides* in general appearance. Cephalon about equal to the following two segments combined, possessing a short transverse sulcus on each side at about the middle distance, posteriorly to which the margins are produced downwards and inwards. Frontal margin of cephalon scarcely produced, incised above the attachment of the second antennæ, forming a small lateral lobe. Eyes sessile, small, round, situated on the dorsal surface near the frontal margin and close to the base of the antennules.

Antennules with three stout basal joints to the flabella, of which latter the upper branch is the longer. The antennæ, with a single flabellum borne on three basal joints, are more slender than the antennules, and somewhat shorter (they are not furnished with a scale). Mandibles with a single, dentate, broad, cutting plate and molar expansion. Eight (?)[2] segments to thorax, the anterior segment fused to the head, leaving seven distinct subequal free segments. Maxillipeds without gnathobasic lobes, endopodite similar to but longer and larger than in *Anaspides*. The thoracic legs which follow carry branchiæ and swimming branches or exopodite, like *Anaspides*. The pleopods are uniramous, except the first two pairs in the male.

The abdomen is of equal length to the thorax, the last segment not longer than the preceding. Anterior portion of body subcylindric in form, becoming gradually rather broader and deeper and cylindrical posteriorly. All the segments of the thorax and abdomen subequal.

Telson entire, slightly broader than long, of triangular form and rounded distally, fringed with spines. Uropoda with peduncle extending to half the length of the telson, its endopodite and exopodite somewhat

[1] See "Description of a new remarkable Crustacean with Primitive Malacostracan Characters," by O. A. Sayce, in the "Victorian Naturalist," Melbourne, vol. xxiv, No. 7 (Nov. 7th, 1907), pp. 117–20; and Ann. and Mag. Nat. Hist. (London), ser. VIII, vol. i (April, 1908), pp. 350–5. [No figure of *Koonunga* has as yet been published.]

[2] This is, of course, a matter of interpretation.

longer than the peduncle supporting them, the inner branch fringed with spines. The largest specimen found measures 9 mm. in length.

The foregoing six genera, comprising two living freshwater forms, namely, *Anaspides* and *Koonunga*, and four fossil forms, namely, *Præanaspides*, *Gampsonyx*, *Acanthotelson*, and *Palæocaris*, notwithstanding various points of difference in details, seem, on general grounds, entitled to be referred to Dr. Calman's order ANASPIDACEA. They all possess a small head (there is no extended carapace). There is evidence that with the head the first thoracic somite was usually coalesced. The eyes were generally pedunculated (as in *Anaspides*),[1] but in *Koonunga* they were sessile, and perhaps in some fossil forms they may have been so also, or even wanting (?).[2]

The antennules are generally large, with two flagella, supported on a stout three-jointed peduncle. The antennæ usually had three basal joints, the third supporting a single flagellum and also an oval scale (exopodite).

Assuming the first thoracic segment to be coalesced with the head, there remain seven free subequal segments each with a pair of walking-legs (endopodites), of which the first was usually much the longest and stoutest; the four succeeding pairs each carried a setose exopodite, and probably also two branchial lamellæ on the basal joint, as in the Schizopoda; but the two hinder pair of legs seem to have been devoid of these appendages. The abdomen consisted of six free subequal segments and a 'telson' or terminal joint; five of these carried pairs of setose pleopods on stout basal joints. The sixth segment (usually a little longer than the preceding, and more or less cylindrical in form) bears the uropods, and to the centre of its posterior margin is articulated the 'telson' or terminal segment, which, with the uropods of the preceding segment, forms the 'tail-fan.'.

Summing up on the question of the fossil genera, referred by Dr. Packard to the Syncarida, namely, *Palæocaris*, *Acanthotelson*, and *Gampsonyx*, Dr. Calman writes (Trans. Roy. Soc. Edinb., 1897, vol. xxxviii (4), p. 801): "We find, then, that *Anaspides* agrees with the extinct genera above enumerated in the essential point in which they have hitherto stood alone: the combination of Podophthalmate characters with a completely segmented body, and the lack of a carapace. We have seen that some at least, probably all, of these genera show characters of the *Schizopoda*, to which group *Anaspides* is most closely

[1] *Anaspides* had also ocelli present on the cephalon; we may therefore consider the eyes in these primitive forms were affected by variable conditions, and we need not necessarily split up the group on that account if the other characters tend to hold them together.

[2] The genus *Koonunga* was not known when Dr. Calman's paper was printed in 1897, nor has a figure of it yet been published (I have, however, been favoured by being allowed to see an unpublished drawing). The absence of pedunculated eyes, etc., has led its author, Mr. Sayce, to propose for it a separate family (the Koonungidæ, under the order ANASPIDACEA), but it seems desirable to await the fuller publication and figure of this interesting crustacean before discussing its separation from the other members of the group. (See Mr. Sayce's preliminary paper, republished in the Ann. and Mag. Nat. Hist., ser. VIII, vol. i (April, 1908), pp. 350–5, with Dr. Calman's note thereon at the end.)

allied. We find probable agreement in such points as the apparent division of the head-region into two segments as by the 'cervical groove' in *Anaspides*. Such differences as have appeared are readily explicable as comparatively unimportant differentiations which might be expected to occur within the limits of the group, or as due to the present imperfect state of our knowledge of the fossil forms. We conclude, therefore, that *Anaspides* is to be regarded as the representative of a group of primitive *Malacostraca*, which had already in Palæozoic times attained a certain degree of specialization and a very wide distribution."

The palæozoologist naturally expects to meet with more generalized and primitive types of structure among the early forms of life discovered in the Palæozoic rocks, but he less frequently hopes to find actual representatives of these ancestral forms surviving at the present day. When such is the case, however, these persistent forms have a more or less worldwide distribution, there being apparently always a corresponding amplitude of measure between the length of past geological time during which a type has existed and its present geographical distribution.

Take, for instance, the 'king-crabs' (Xiphosura), we have evidence of their existence from the Upper Silurian to the present time, and they attain the same wideness in their life distribution now. The Scorpionidæ also enjoy equal geological antiquity and even wider modern geographical extension.

The common 'River Cray-fish,' *Astacus fluviatilis*, with its marvellous worldwide distribution,[1] had its undoubted representatives in the Chalk, Jurassic, and Trias, which in turn derived their origin from the more generalized forms of Anthrapalæmonidæ of the Coal-measures.

After the discovery by G. M. Thomson of *Anaspides* living in freshwater pools on Mt. Wellington, Tasmania, at an elevation of 4,000 feet above the sea, and of *Koonunga cursor* by O. A. Sayce near Melbourne, Australia, we may probably learn of the existence of similar persistent simple congeneric Schizopod-like forms in the freshwaters of remote and widely separated parts of the globe, just as we know of their past life-history in the widely distributed Carboniferous strata of Britain and the continents of Europe and America.

II.—The Old Red Sandstone of Forfarshire, Upper and Lower.

By George Hickling, B.Sc., Lecturer in Geology in the University of Manchester.

(PLATES XX and XXI.)

Introduction.

During the past ten years I have spent much time on the cliffs of the Forfarshire coast, and to the magnificent sections of the Old Red Sandstone therein displayed I owe very largely my interest in geology. In the neighbourhood of Arbroath the well-known unconformity between the upper and lower members of that series is admirably

[1] See "The Cray-fish," by T. H. Huxley, F.R.S. (1880), pp. x and 372, with 82 illustrations. Kegan Paul & Co. 8vo.

exposed. The magnitude of that break has been insisted on by many writers, but no description, I think, could be quite so impressive as those cliff-sections. Moreover, of late years, there seems to have been a tendency in many quarters to minimise its importance. In most localities the relation between the two sets of rocks is a matter of inference rather than observation. This fact at once explains the willingness to pass lightly over this unconformity, and at the same time makes it the more desirable to have an adequate description of a locality where its magnitude can be clearly seen.

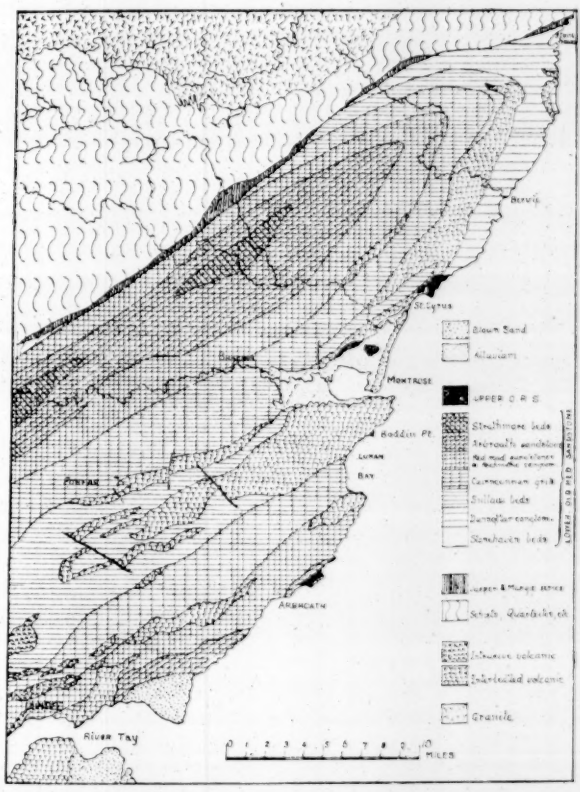

Fig. 1.—Sketch-map of the Geology of Forfar-shire.

Note.—This map is to a considerable extent hypothetical, especially in Kincardine, but I believe the general distribution of the various subdivisions is in the main correct.

The attempt to collect and review the published work bearing on this question soon proved that no satisfactory result could be attained without a complete investigation of the wide and involved question of the relation of the Old Red Sandstone and Carboniferous deposits. This carried me far beyond the limits I had originally conceived for this communication, and it became obvious that the subject must be

treated in at least two distinct parts—the present one, dealing with the rocks in Forfarshire, and a subsequent one in which I hope to discuss the more general question.

It would be impossible properly to realise the magnitude of the unconformity in Forfarshire without a preliminary knowledge of the general succession and tectonic structure of the Lower Old Red series in that locality. Notwithstanding the fact that the series is believed to reach there a greater thickness than anywhere else in Britain, no adequate description exists, and hence I need make no further apology for the brief sketch which forms the first section of this paper.

General Features of the Lower Old Red Sandstone.

The counties of Forfar and Kincardine are sharply divided into highland and lowland sections by the line of the great Highland fault, running south-west from the coast at Stonehaven, and bringing down the Old Red to the south against the schists and granites on the north. The Old Red underlies the whole of the lowland tract. Between the foot of the highlands and the valley of the Tay the low ridge of the Sidlaws intervene, with Strathmore between it and the highlands. These physical features are directly related to the folding of the subjacent rocks. Against the highland fault the sandstones and conglomerates lean almost vertically. After a couple of miles or so the dip rapidly becomes lower, and the synclinal axis is reached, which follows the line of Strathmore. South of the axis the dip in the reverse direction increases to about 25°. It afterwards decreases, and again changes its direction beyond the anticlinal axis which runs along the Sidlaws. On the southern limb of the anticline the dip again rises to about 25°. This pair of folds may be traced right across Scotland, the axes remaining sensibly parallel to the highland fault the whole way, pointing, no doubt, to the simultaneous production of fault and folds. These folds have been familiar for three-quarters of a century, having illustrated the terms 'anticline' and 'syncline' in Lyell's "Elements." There is, however, another, but much less obvious, series of folds affecting these rocks, with axes running north and south. The influence of these is usually slight, but about Stonehaven an anticline of this series brings up rocks much lower than would otherwise be exposed—the lowest, indeed, in the district.

With each of the two series of folds just referred to there is a series of faults associated, some of which are marked on the Survey map. For the most part, however, these are small, and I do not think they need further comment.

Table of the Lower Old Red of Forfarshire.

	Feet.
Edzell Shales	2000
Arbroath Sandstone	1200
Auchmithie Conglomerate	800
Red Head Series	1500
Cairnconnan Series	2000
Carmyllie Series	1000
Dunnottar Conglomerate	5000
Stonehaven Beds	1500
	14,000

It must be remarked that the subdivisions in the above table are based purely on lithological characters and are only made for convenience of description. No breaks in the series exist to my knowledge, and I am far from supposing that these subdivisions are likely to be traceable for any great distance; rapid lateral variation in the character of the rocks is too obvious a feature of the Old Red Sandstone. The names applied to the subdivisions are taken from the localities where the series may be typically seen. The thickness of the subdivisions are estimated from theoretical sections for the most part, and are therefore to be regarded as only approximately accurate.

The Stonehaven Beds occupy the shore between the harbour of Stonehaven and the south end of Craigeven Bay, where the great fault is exposed. A mass of fault breccia fully a yard in thickness occupies the line of junction, while the rocks on either side of it are shattered for fully four yards. Fine red sandstone, with numerous thin bands of bright red shale, is the first rock seen on the south side, dipping at about 60° to S. 12° W. Further south several beds of the red marly shale, 50 to 100 feet in thickness, separate light red or yellow sandstones and fine grits, with some bands of grey sandstone and grit. Such is the general character of the series, which is distinctly *fine* in character as compared with the mass of the Old Red. About midway between the fault and the town the Lintrathen porphyry dyke cuts across the shore. The dip varies somewhat both in amount and direction, but is always very high, and no important break in this section appears to exist. About the harbour bands of conglomerate appear among the sandstones, marking the passage to

The Dunnottar Group of coarse red and grey sandstones, grits, and conglomerates which form the bold coast the whole way from Stonehaven to Johnshaven. As I have only been able to examine the base and the top of this series, I shall add no more than that it forms by far the most extensive series of conspicuously coarse deposits in the district. In its conglomerates pebbles commonly range up to a foot or more in length, and yet are astonishingly well rounded. They mostly consist of quartzite. South of Johnshaven several thin lavas are interbedded with the top of this series, with sandstones and coarse conglomerates of porphyrite blocks between. Beyond this the coast-section is interrupted by the mass of Upper Old Red which is faulted in, extending from East Mathers to Milton Ness (described below), and which covers the junction between the conglomerate series and the great mass of lavas which forms its natural top. These lavas occupy the coast southward by Montrose to Lunan Bay, being hidden, however, almost the whole way to Montrose by sand and alluvium. From Lunan Bay their outcrop strikes inland along the summit of the anticline by Friockheim and Letham, near which latter place they finally die out. About Friockheim and Leysmill are numerous quarry sections of the

Carmyllie Series, which overlies the lavas. Compact red or grey sandstone is the predominant rock of this series, with subsidiary masses of grey flagstone and blue or red shale, termed 'caulm' by the quarrymen. Together with their interbedded lavas, these rocks form the whole axis of the Sidlaws, all along which they are quarried

for building and paving material. The well-known Carmyllie quarries are in the middle of this series. Passing upward, the

Cairnconnan Series is reached, distinguished by its coarser materials, principally dull red or grey grit with bands of conglomerate. The conglomerates are more particularly developed on the north side of the anticline, as at Turin Hill, north of Rescobie Loch. This series should appear on the coast in Lunan Bay, but it is entirely hidden by the sand and alluvium. At the south end of the bay another series of lavas, admirably exposed for study, intervenes between it and the

Red Head Series, which forms the bold cliffs from the promontory of that name southward to Rumness. In its lower part it consists of fine red thin-bedded sandstone with bands of hard bright red shale, while the upper portion is made up of thicker-bedded sandstone. Some six or seven miles to the south-west, at Arbirlot, the lower part of this series, as seen in the banks of the Elliot Burn, consists mainly of blue and grey shales, with partings of sandstone, having so strong a resemblance to some of the rocks of Carmyllie as to have led Hugh Miller to consider them as a repetition of that series. This case illustrates very well the rapid lateral variation to which all the beds of the Old Red Sandstone are liable.

The Auchmithie Conglomerate overlies the previous group in the cliffs just north of the village so named. The series consists of three main masses of conglomerate, with intervening sandstones and conglomerates. The pebbles in the conglomerates are well rounded, fairly large (generally 1 to 6 inches, rarely 12 inches), and, as usual, are mostly quartzite. The thickness of this conglomerate series diminishes along its outcrop to the south-west.

The Arbroath Sandstone is the highest series of the Lower Old Red seen on the Forfarshire coast. Coarse, gritty, sometimes pebbly sandstone is its component rock, always red in colour. Just above the base of the series, by the Signal Tower at Arbroath Harbour, there is a single band of grey grit and marlstone on the shore, containing nodules of limestone from the size of a pea to 1 foot in diameter. This is noteworthy in view of the almost complete absence of lime from the Lower Old Red System. In Strathmore the Geological Survey traced a thin bed of limestone for some miles, and, as far as I can judge, that bed occupies about the same horizon. If they should prove to be the same they would form a valuable datum-line in correlating the beds north and south of the anticline—at present a very difficult matter. In the few old descriptions of the rocks of this district other limestones are referred to (Powrie, 1861), but these are either in the Margie Series (Barrow, 1901) or in the Upper Old Red.

The Edzell Shales lie in the more depressed parts of the synclinal trough of Strathmore, but are not represented, so far as I am able to judge, south of the anticline. They overlie the Arbroath sandstones. They are generally bright red fine sandstones, shales, and marls, either hard or soft, frequently mottled with small circular patches of pale yellow, grey, or green, or more rarely with bands of the same colour. These rocks are admirably displayed in the banks of the North Esk at Edzell, and even better in the South Esk, below its junction with the

Prosen, about Shielhill Bridge. They are the highest beds which, to my knowledge, the system presents in this district.

The volcanic rocks of the district do not call for description here. It may suffice to remark that they are, with very rare exceptions, in the form of contemporaneous interbedded sheets, and are merely a continuation of the series of the Ochil Hills, where they have been described in detail by Geikie and others (A. Geikie, 1900).

Position of the Fossil-bearing Beds.

Attention must now be drawn to a point, the importance of which has not, I believe, been hitherto recognised. All the recorded fossils from this district—and I suspect that the same applies to Perthshire—are from a very limited series of horizons near the middle of the Lower Old Red System, the Upper Old Red being, of course, left out of account. The Carmyllie series is the fossiliferous group *par excellence*, while a few of the worked localities may lie in the Cairneonnan series (e.g. Tilliewhamland quarry, Turin Hill), or the top of the Dunnottar conglomerates. Odd fossils have occasionally been obtained from other horizons, but they are quite a negligible quantity.

The palæontological evidence as to the age of this Lower Old Red System, then, as here developed, can only be affirmed of its middle beds; to apply it to the whole system, as has been implicitly done, is obviously unjustifiable. Geikie has stated that these rocks may reach a maximum thickness of 20,000 feet, which cannot be any great exaggeration. The Oreadian Old Red he estimates at 16,000 feet; then follows a considerable unconformity not represented by any deposits, in Scotland at least, and some 2,000 feet of Upper Old Red above that. Add these up and we obtain the modest sum of 38,000 feet with a great unconformity, or certainly the equivalent of over 40,000 feet of strata to represent the Old Red Sandstone! Small wonder Sir A. Geikie shrank from admitting such a thickness, and turned to Austen's hypothesis of isolated lake-basins to account for the difference of the 'Caledonian' and 'Oreadian' faunas, without having to superpose the latter rocks on the former!

Unfortunately for this solution of the difficulty it is becoming more and more obvious that the hypothesis is untenable. The objections fall into two categories—physical and palæontological. Those of the former class were well stated by Macnair & Reid in 1896 (M. & R., 1896). At Towie, in Aberdeenshire, an outlier of 'Oreadian' Old Red approaches within barely twenty-five miles of the main mass of the Caledonian deposit; and this outlier, like that of Tomintoul a little further west, is actually on the Grampian ridge which must have separated the two Old Red basins, so that it is very improbable that at the time when it was deposited the ridge was in any important degree higher than at present. Bearing in mind this fact, it is only necessary (as pointed out in the paper just referred to) to replace the Caledonian deposits in their original position, as before they were faulted down, to see that all the higher beds must pass over the Highland ridge to join the Oreadian series.

The palæontological evidence was fully appreciated by Murchison (1859) and Salter (Salter, 1863), who based their conclusion that the fossiliferous horizons of Caithness were higher than those of Forfarshire on a comparison with the continental Devonian and Old Red rocks, as is so well known. That conclusion is now greatly strengthened by the patient work of Traquair, who regards the question rather from the biological side. From that view, the evidence may perhaps best be summarised thus: The fishes of the Orcadian Old Red are undoubtedly more nearly allied to those of the Upper Old Red than are those from the Caledonian rocks; while, on the other hand, the Forfarshire fossils bear a much greater similarity to those of the highest Silurian beds than do those of Caithness. These facts, then, fully bear out the conclusion of Murchison and Salter. Goodchild vigorously advocated this view in a paper written shortly before his lamented death (Goodchild, 1904), and, for a fuller analysis of the palæontological data, reference may be made to the exhaustive account by Evans (Evans, 1891). As this latter paper may not be readily accessible, it may be stated that he finds that of the thirty species of fish in the Orcadian Old Red, six occur in the Upper Devonian of Russia. A single species is very doubtfully common to the Forfarshire rocks. Of the eighteen genera, ten occur in the Upper Devonian or Upper Old Red. One genus is common to the Lower Old Red, and two others very doubtfully so. I think it may safely be added that the work done since 1891 has at least fully confirmed this distinctness of the Caledonian and Orcadian faunas (Horne, 1901).

Two points thus seem clear: it is physically impossible that the two areas of Old Red under consideration could have been entirely deposited separately, yet the faunas are entirely distinct, and the nature of the faunal difference is such as to indicate that the Orcadian fossil-beds are higher than the Caledonian. In other words, the fossiliferous deposits of Caithness *must* be superposed on those of Forfarshire. But that is quite a different matter to saying that 16,000 feet of Old Red in the north must be superposed on 20,000 feet in the south. In Caithness the lowest 4,000 feet or so appear to be unfossiliferous, or practically so (lower part of Wick group, below Achanarras, and the lower Sandy and Conglomeratic groups), and hence 12,000 feet will be a liberal estimate for the thickness, which includes all the fossiliferous horizons, even on Geikie's estimate, which Evans, in the paper referred to, considers too great. In Forfarshire I have pointed out that the fossil-bearing strata are confined to the Cairnconnan and Carmyllie series, with a combined thickness of certainly under 4,000 feet. Hence 16,000 feet will be a generous estimate of the united thickness of the fossiliferous beds of the two areas. The 4,000 or 5,000 feet above the highest fossil-bearing zone in Forfarshire and the 4,000 below the lowest in Caithness count for nothing.

It will be remarked that there is still some 6,000 or 7,000 feet of strata below the fossiliferous band in Forfarshire to be dealt with. Regarding these I would say that as they have as yet yielded no fossils it is impossible to say definitely what their age may be, except in relation to the beds above.

Upper Old Red Sandstone.

The main mass of this deposit, in Northern Fife and the Carse of Gowrie, has been several times described, most recently by Sir A. Geikie in his "Geology of Western Fife and Kinross" (A. Geikie, 1900), and therefore needs no further description here. The small outliers, however, along the coast of Forfar and Kincardine have never received attention.

There are four of these patches, which obviously represent the remnants of a once continuous strip along the shores. The most southerly is near Arbroath, the next forms the tiny promontory called Boddin Point, at the north end of Lunan Bay, while the third (which is largely covered with alluvium) and fourth form a broken strip from the north side of the Montrose Basin to near Johnshaven. It is clear, therefore, that this deposit was originally a continuous and almost perfectly horizontal sheet. On the Survey map dips may be seen marked in this deposit up to as much as 15°, but these are quite erratic, and are doubtless due entirely or almost entirely to current-bedding; there is no sign of any such irregular folding in the older series of rocks.

The identification of these outliers as belonging to the Upper Old Red depends on their lithological character and general tectonic relations, no fossils having been found in them.

Tectonic Relations.

These rocks are clearly younger than the folding which has affected the subjacent Lower Old Red, and also later than a good deal of the denudation which followed it. Before the horizontal strata of Montrose and Boddin Point were laid down there must have been not less than 8,000 feet of rock worn from the top of the Lower Old Red anticline. This must, no doubt, be held to imply a great break between those two sets of rocks.

Precisely the same relation, however, holds between the Upper Old Red of the Carse of Gowrie and the rocks below. That mass also lies directly over the Lower Old Red anticlinal axis, and can therefore only have been deposited after a similar amount of denudation. The type-specimen of *Holoptychius nobilissimus* was obtained from those beds, so that their age admits no question.

It will be desirable to illustrate this unconformity more fully when the lithological character of these coast deposits has been described, and its bearing on their age considered. Meanwhile it is clear that their tectonic relations are exactly similar to those of the most undoubted Upper Old Red.

Lithological Characters.

Two distinct types of sedimentation occur in these rocks—the sandy type and cornstone type. The former alone is developed in the mass near Arbroath, where it reaches a thickness of about 200 feet. The materials of this deposit are precisely similar to those of the Lower Old Red on which it lies, and from which it has no doubt been derived. Fairly soft red sandstone, with numerous bands of conglomerate, which are usually thin and irregular, occasionally thicker

and more persistent, is a fair description of the whole deposit. In a broad view, the whole mass would be described as a conglomerate. No trace of calcareous material is present, except in the form of veins and patches of calcite (e.g. about Whiting Ness). These veins are of value as indicating that there have formerly been calcareous strata overlying these beds, as would be expected from a comparison with the deposit in other areas.

I have carefully searched through the pebbles in the conglomerates for evidence on the age of these rocks, but with only negative results. There appear to be no pebbles of later age than the Lower Old Red, and this fact so far confirms the Upper Old Red age of these beds.

In the other two exposures of this series of rocks on the coast, viz. at Boddin Point and St. Cyrus, the lower part of the section shows red sandstone, the upper cornstone. At Boddin Point the series is brought down by a strong fault against the porphyrites, the fault being beautifully exposed on the south side of the headland. About 40 to 50 feet of quite soft yellow or white sandstone, mottled with light red, is exposed below the cornstone, while the base of the series is thrown below sea-level. Above this sandstone we have the following beds, No. 1 being the sandstone itself:—

	Feet.
(11) Hard brecciated very calcareous sandstone	1
(10) Mottled purple sand-stone	1
(9) Hard compact calcareous sandstone	2
(8) Fine sett mottled purple sandstone, with irregular limestone nodules	3
(7) Mottled purple sandstone	4
(6) Yellow brecciated sandstone, with dendrites	5
(5) Mottled yellow and red sandstone...	10
(4) Brecciated yellow dolomite, with dendrites	3
(3) Mottled sandstone	4
(2) Yellow dolomite, with dendrites	1
(1) Yellow and mottled sandstone	40

The terms used in the above table are the best I could find to briefly indicate the nature of the various beds, but accurate description is exceedingly difficult. As to the nature of the materials composing the rocks, every mixture may be found between a pure sandstone and an almost pure limestone, as I have ascertained by actual estimation of the quantity of lime in various specimens. And as to the structure of the rock, there is still further difficulty. All the beds described as 'brecciated' have the appearance of typical breccias on a weathered surface, but on a fresh fracture the same rock frequently appears perfectly compact and even. In such cases I believe the brecciated appearance is entirely due to crystallisation in the limy matrix. In other cases the brecciated character is still evident, though far less prominent, on the broken surface, and in those instances it would seem to be due to the breaking up and re-consolidation of the deposit during its formation. Very seldom is the material a true breccia. Here and there, however, pebbles in one bed have evidently been derived from the break-up of a lower stratum. Irregularity and discontinuity of deposit are further evidenced by strongly developed false-bedding, by local erosion of beds (No. 6, for example, is in

places completely removed), and by the fact that the beds are so irregular that they cannot all be traced from one side of the little promontory to the other.

In the more extensive outlier at St. Cyrus essentially the same rock-types occur but in much greater thickness. The 'cornstone' type is there probably 40 to 50 feet in total thickness, and is covered in turn by another 30 feet of sandstone. The cornstones include a beautiful band of flesh-coloured calcareous sandstone, in which the limy matrix forms crystals up to about half an inch in diameter, the quartz grains being included. The sandstones below pass down into red sandstone with conglomerate exactly similar to the rocks at Arbroath. I have not been able to make a sufficiently detailed examination to estimate the thickness, which could only be ascertained by careful mapping.

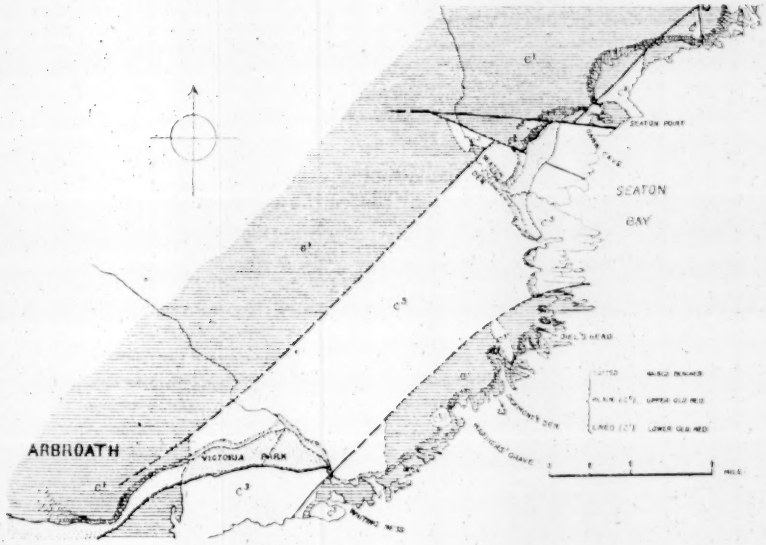

FIG. 2.—Map of the Outlier of Upper Old Red Sandstone near Arbroath.

The base of the series here, again, is unfortunately not exposed. The junction of the outlier with the porphyrites at the south end is a beautiful fault, not a natural boundary as shown on the Survey map. At the north end the junction with the Lower Old Red conglomerates is either a fault or the Upper series is banked up against an old cliff of the Lower.

It is clear from the description which has now been given of these outliers of Upper Old Red that their lithological characters are exactly those of the typical Upper Old Red—red sandstones at the base, passing up into more variegated calcareous sandstones and marls. The upper or cornstone type has long been recognised as indicating peculiar conditions of formation; what the conditions were we are

not here concerned with. In view of what has already been said regarding the tectonic and geographical relations of these deposits, it can, I think, scarcely be doubted that the peculiar conditions which led to the formation of this rock-type here were in the main contemporary with the corresponding conditions in Fife and the Carse of Gowrie. It would be foolish to contend that the base of these outliers is on precisely the same horizon as the base of the series in other localities, but I think it must be admitted that these rocks are of Upper Old Red age, which is the only point of importance.

The Unconformity between the Upper and Lower Old Red.

Having now examined the evidence proving that these outliers are of the same age as the typical Upper Old Red of Fife, we may profitably examine more fully the relation of the deposit to the Lower series, where it is so admirably displayed in the cliffs of Arbroath.

The accompanying sketch-map shows, in addition to the main mass of the deposit let in between a pair of faults, numerous small patches which lie undisturbed in depressions in the ancient surface of the Lower Old Red. The actual junctions of the Upper and Lower series are, moreover, exposed in numerous places, and thus a very fair idea of the old surface may be obtained. In the south-west of the map, on the foreshore opposite Victoria Park, the junction may be traced right across the shore, the Upper beds sometimes abutting against a vertical face of the Lower, while in other places they extend horizontally over them. At Whiting Ness, again, the junction may be traced for several hundred yards in the foot of the cliff and on the shore. The surface of contact is nearly horizontal and fairly even until the eastern limit of the Upper beds is reached, where they end off against a high bank of the Lower strata, which is cut in section by the present cliff and rises its whole height (Pl. XX, Fig. 1). In the base of the Upper beds west of the foot of this old bank, angular blocks of the sandstones of the Lower series more than a yard in length are included. Another fine example of the Upper series resting against a steep bank of the Lower is to be seen at Seaton Point, where the main fault forming the north-west boundary of the former is also admirably exposed (Fig. 2), the Dark Cave being drilled through the Point along it. On the east side of Dickmont's Den two troughs cut out in the Lower beds are seen in section in the cliff filled in with the conglomerates of the Upper series. But by far the finest example of a valley cut in the older series is to be seen in an inlet in the cliff in the extreme north-east of the map, and on the west side of Lud Castle (just off the map). There the horizontal Upper beds fill a V-shaped depression over 100 feet in depth.

It appears from these instances—and others might be added—that the old surface on which this mass of Upper Old Red rests is a distinctly irregular one, in every way a typical old land-surface.

This fact is of considerable value in estimating the significance of this unconformity. Those wishing to minimise the importance of this break might suggest that the folding and erosion of the Lower Old Red proceeded *pari passu* with its deposition, and that though the break appears great where the Upper series oversteps on to the lower beds of the Lower series, in the centre of the anticline, yet the

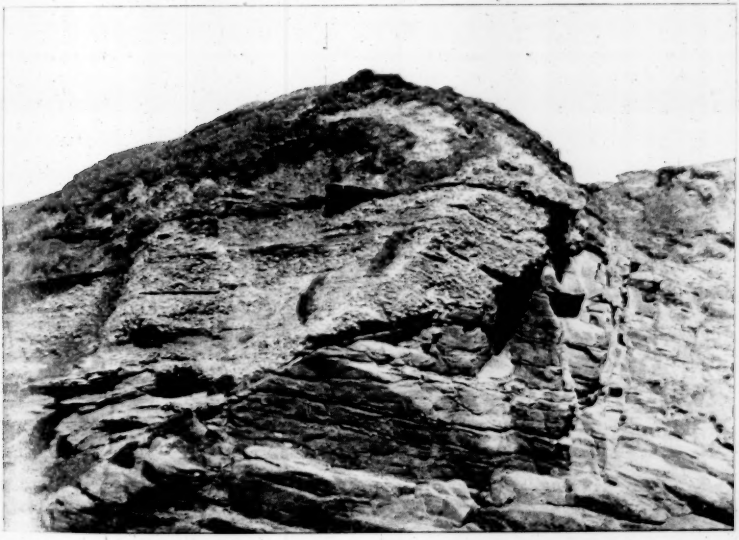

Fig. 1.—Junction of Upper and Lower Old Red Sandstone, Whiting Ness.
Fig. 2.—Upper and Lower Old Red at Seaton Point, fault at the Dark Cave.

discordance might be small or non-existent between the top members of the Lower and the base of the Upper. The sections here described furnish a complete answer to this objection. The beds on which the Upper series here rests are the Arbroath sandstones, near the top of the Lower series. They are dipping at 20°–25° to the south-east—the maximum inclination shown on this side of the anticline—while the irregular surface on which the Upper series rests is broadly horizontal. Hence it is perfectly clear that—

(1) The folding of the Lower series was subsequent to the deposition of the *whole* of that series.

(2) The extensive denudation by which the anticline was planed off flat was entirely subsequent to the deposition of the whole Lower Old Red.

(3) The deposition of the Upper Old Red was subsequent to the folding and denudation.

There remains the question whether this folding and denudation can be referred, wholly or in part, to the period of the Orcadian Old Red. The only facts which may help to a conclusion on this point are these: The upper beds of the Forfarshire Lower Old Red, to which the folding is certainly subsequent, probably are the equivalents of part or the whole of the Orcadian series; either that, or we must admit the enormous total thickness of the Old Red, which is the difficulty so often felt before. It should be noted, too, that no natural top to the Caledonian series is anywhere seen, so that there is certainly no evidence that sedimentation ceased in that area any sooner than further north. Again, we have the fact that the Upper Old Red of the Moray Firth, some of which has been concluded, on palæontological grounds, to be older than that of Fife (Horne, 1901), is itself generally considered to rest unconformably on the Orcadian series. It would seem, therefore, that though it is just possible that a part of the great interval of time represented by this unconformity in Forfarshire may be accounted for by the Orcadian deposits, a large part of it at least must have been subsequent to the formation of those beds. The magnitude of the unconformity in Forfarshire has been sufficiently demonstrated. Its magnitude elsewhere and its general significance must be discussed in a subsequent communication.

Summary of Conclusions.

The Lower Old Red Sandstone of Forfar and Kincardine is upwards of 14,000 feet in thickness. No indication of a base or natural top is seen in the district. The characteristic fossils of this series have all been obtained from its middle beds within a vertical range of less than 4,000 feet. There is no palæontological evidence of the age of the beds above or below that zone. It is concluded, on physical and palæontological grounds, that the fossiliferous beds of the Orcadian area are really younger than those of Forfarshire, but there is no proof that the higher part of the Forfarshire series was not contemporaneous with the Orcadian deposits.

The folding of the Lower Old Red strata into the syncline and anticline parallel to the Highland boundary fault took place subsequently to the deposition of the *whole* of those strata. This folding,

and denudation to the extent of 8,000 feet over the anticlinal axis, were accomplished after the deposition of the Lower and before the beginning of the Upper Old Red. The surface on which the Upper Old Red rests, in Forfarshire, is broadly horizontal, but very uneven—evidently an old land-surface.

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EXPLANATION OF PLATE XX.

Fig. 1.—Photograph showing horizontal Upper Old Red conglomerate resting against inclined surface of Lower Old Red. The full dip of latter beds is not seen. The lower part of the Upper Old Red on the left consists of soft sand-stone. Cliff 200 yards east of Whiting Ness. Height of cliff about 50 feet.

Fig. 2.—Upper Old Red (on right) faulted down against Lower (on left) at Dark Cave, Seaton Point. Height of cliff at fault, 140 feet. At the extreme point the inclined beds of the Lower series are seen rising from under the Upper. On the other side of the Point the junction may be seen to be similar to that in Fig. 1.

EXPLANATION OF PLATE XXI.

Fig. 3.—Photograph of Upper Old Red conglomerate at Cove Haven, Seaton Bay. Height of cliff in photo about 10 feet.

Fig. 4.—Cliffs at Cove Haven, Seaton Bay, showing general character of Upper Old Red of this outlier. Height of cliff in foreground about 50 feet.

III.—The Gavarnie Overthrust, and other Problems in Pyrenean Geology.

By E. E. L. Dixon, B.Sc., F.G.S.

(*Concluded from the August Number, p.* 373.)

Of the places where undisturbed limestone rested on older rocks, the most important visited by us was the valley of Hount-Sainte on the Spanish slope. This does not appear to have been considered by Carez, nor to have been hitherto described in detail. The following sequence is clearly exposed, in descending order:—

4. Palæozoic—Devonian and Carboniferous according to Bresson. Shales and limestone in the lowest part, the base evidently a plane of disturbance.

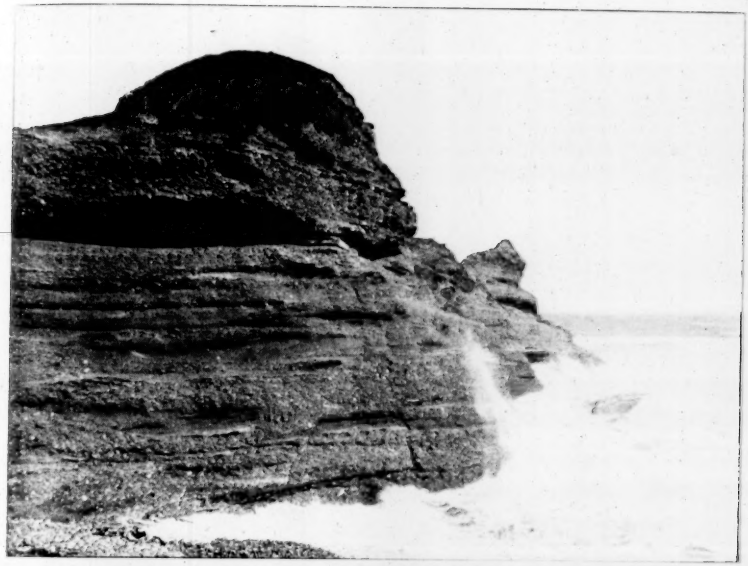


FIG. 3.—Upper Old Red Conglomerate, Cove Haven, Seaton Bay.
FIG. 4.—Upper Old Red Sandstone Cliff, Cove Haven, Seaton Bay.

3. Cretaceous (Campanian). Rubbly, thick-bedded, partly dolomitic, white limestone with hippurites, etc., the base, which contains many angular quartz-fragments, showing no signs of disturbance.

2. Permo-Trias. Chiefly micaceous shales, red on the whole, but partly changed to buff and green at the top; also some fine-grained sandstones, and, at the base, several feet of quartzitic sandstones and conglomerates of subangular quartz-fragments. Total, about 50 feet.

1. Basement-platform. Granite and mica-schist, worn down to an even surface to which Permo-Trias and Campanian are parallel, both as a whole and in individual beds.

Carez, in discussing the relations of the Campanian to underlying rocks, does not refer to the fact that on the Spanish side it is underlain by Permo-Trias, and consequently does not consider the relations of these two, but it is a necessary consequence of his theory that the former should be regarded as thrust over the latter. But here the rocks immediately beneath the supposed overthrust do not form a rigid platform as in the cases considered by Carez, where their abrupt truncation lent colour to his supposition; on the contrary, they consist of soft beds on which the limestones rest with apparent conformity, and, although the one group would be much less rigid than the other under the influence of lateral pressure, neither shows any sign of differential movement either within itself or relatively to the other. Also, the fact that the basement-platform of crystalline rocks passes beneath the Permo-Trias shows that it has not been planed down by an overthrust, as there is no evidence of such movement of the beds which are there resting on it.

In view of these facts and their bearing on Carez' arguments, we have concluded that the Cretaceous in the neighbourhood of Gavarnie has not been overthrust. The same is probably true of the Cretaceous elsewhere in the same region, for it is on the strength of the evidence already discussed that Carez relies largely when he says, "Le Crétacé supérieur de Gavarnie, du Balaïtous, des Eaux-Bonnes et du pic Bazès n'est pas en place, et ces lambeaux sont les restes d'une immense nappe de charriage venue du Sud et qui se montre . . . depuis Eugui jusqu'au rio Flamisel, sur une largeur de plus de 200 kilomètres." (Eugui and the river Flamisel are, respectively, far to the west and east of Gavarnie.) As Gavarnie lies nearest the roots of this supposed overthrust and at about the middle of its length, the undisturbed state, in places, of the Cretaceous there, appears to us to invalidate Carez' overthrust, and with it Termier's conclusion, based on Carez', that the whole Cretaceous of the Pyrenees has been 'carted' from the south. It appears, therefore, that a very useful service has been performed by Mr. Stuart-Menteath in protesting against the wholesale invocation of *charriages* if they are supported by no better evidence than in this instance.

The third problem we shall discuss relates to the age of the crystalline rocks of the basement-platform below the Cretaceous in the Gavarnie (Pau) and Héas valleys, and is of more than local interest as it raises the old question whether gneisses and schists, to all appearance Archæan, may in reality be Palæozoic or even younger.

The rocks consist of mica- and quartz-schists, containing an

abundance of secondary minerals, such as biotite, garnet, cordierite, sillimanite, etc., with, here and there, crystalline limestones, the whole injected with a plexus of plutonic rocks; they evidently, as MM. Michel Lévy and Lacroix have already stated,[1] represent a sedimentary series which has been profoundly modified by thermal metamorphism. However, the rocks which crop out over the whole area enclosed by the Cretaceous of the above valleys (Fig. 2) show no general diminution of metamorphism in any direction to guide us to the unaltered originals; they have, in fact, been completely recrystallised throughout, and are so abundantly and intricately veined with gneisses and granites that it is often difficult to say whether the heterogeneous resultant is a mass of granite crowded with enclosures or a mass of sediments crowded with veins.

The resemblance of this sedimentary and igneous complex to the fundamental rocks of other parts of the world led the older writers, Ramond and De Charpentier amongst others, to refer them to the 'primitive' series (our Archæan), at that time regarded as part of the original crust or as crystalline sediments of a primæval sea. Bresson, however, points out that Lévy and Lacroix have adduced evidence of the production of these schists from normal sediments, and goes on (op. cit., pp. 39, 160–163, 167–169, 181–184, 194–197) to give reasons for regarding the age of the sediments in this case as Ordovician, and of the granites which have altered them as Hercynian (post-Carboniferous, but pre-Triassic), though he states at the same time (p. 197) that both groups differ in no respect from Archæan rocks. The evidence he cites is as follows. The rocks in question, though occurring as an inlier in the Cretaceous without visible connection with neighbouring Palæozoic outcrops, lie in the course of a belt of metamorphism which he has traced in a westerly direction to within a short distance of them, through an area composed entirely of Palæozoic rocks (see Fig. 2). This metamorphism is generally characterised by considerable reconstruction of the sediments, e.g., the production of secondary mica, sillimanite, and large chiastolites, and appears to increase in intensity westward towards the Géla, where the rocks (Ordovician slates) become highly micaceous and crowded with chiastolite, and pass into leptynolites. At the same time a great number of veins of quartz, pegmatites, and 'micro-granulites' [quartz-felsites] appear. Hereabouts the sedimentary and igneous rocks form the basement-platform of the Cretaceous, beneath which they disappear westward. At a short distance in that direction the platform reappears in the Héas and Pau valleys, where, however, it is composed of the rocks whose age is in question. The relationship of the latter to the metamorphic rocks of the Géla cannot, therefore, be determined directly, as the change occurs below the Cretaceous, but the relative positions and degrees of metamorphism of the two series of altered rocks has suggested to Bresson that those in the Héas and Gavarnie valleys are continuous beneath the Cretaceous with those to the east, a conclusion which is supported, in his opinion, by observations in the valleys themselves. Thus, in several places, such as the Cirque de

[1] Bresson, op. cit., p. 160.

Troumouse, Silurian slates thrust over the Cretaceous (as shown in Pl. XVIII, Fig. 2) contain abundant chiastolite, and though not in their original position they doubtless, he says (p. 162), come from the deep-seated margin of the schists. But he attaches the greatest weight to the reported occurrence, within the granite-plexus, of masses of unaltered slates and quartzites, as well as the schists, in one of which at la Prade de Saint-Jean, between the village and the cirque of Gavarnie, *Calymene Tristani* is said to have been found (pp. 39 and 162) by the elder Frossard.[1] He further points to the close petrological affinity of the Gavarnie-Héas complex to that of Caillaouas, which, though at some distance to the east, is connected with the other by the belt of metamorphism previously mentioned, and in the neighbourhood of which Devonian rocks themselves have been metamorphosed (p. 163). As this suggests that the Gavarnie-Héas granite itself is post-Devonian, and as throughout the district he finds little evidence of large earth-movements prior to the Hercynian folding, such as elsewhere precede pre-Carboniferous intrusions, but on the other hand can prove that the Hercynian mountain-building was followed hereabouts by the irruption of granite masses into various formations, he concludes that the Gavarnie-Héas and the Caillaouas granites are themselves Hercynian (p. 169).

His evidence does not, however, appear to be conclusive. The increase in intensity of the metamorphic belt westward is not necessarily due to our approaching the Gavarnie complex, but is sufficiently explained by the fact, unknown to Bresson when he published in 1903 the work to which we have been referring, that granite is present in the higher part of the Géla Valley, where, as stated above, the metamorphism of the belt becomes very intense. It is shown on the Luz sheet of the Carte Géol. Dét., published in 1906, and appears to have been found by Bresson himself, as it is included in that part of the sheet surveyed by him. It is represented (see Fig. 2) as a westward continuation of the Bielsa granite, which lies to the south of the belt. The belt itself is due to granite, apparently an offshoot of the Bielsa mass, which just reaches the surface at the Pic de Lustou. We must ascertain, therefore, whether the Gavarnie granite may be regarded as a continuation still further westward of the Bielsa mass, and with that view we shall now compare the rocks of the two places, as their relationship is not directly determinable.

The Bielsa granite appears as a large, uniform, and coherent mass

[1] The original record does not state very clearly the exact source of this specimen, and on that account the conclusion drawn from it has appeared to be of limited value, but fortunately the specimen itself is still in existence, and has been examined by Stuart-Menteath, who has questioned the identification in his "Pyrenean Geology," and, more recently, by Bresson. The former has kindly supplied the following extract from Bresson's remarks in the recently published final part of the Bull. Soc. Géol. France, tome vi, which contains an account of an excursion of the Society to Gavarnie, and which has appeared since these notes were written:—"Mais l'examen de ce fossile a montré qu'il provient, d'après ses caractères et d'après la composition de la gangue, du Coblenzien du pic de Mourgat, dont les éboulis récouvrent les pentes de la Prade et qu'il appartient au genre Phacops (*Phacops* aff. *Potieri*, Bayle)." In view of these views of Stuart-Menteath and Bresson the fossil evidently has no bearing on the question of the age of the schists.

of ordinary granite on the Carte Géol. Dét. It was examined by us during a traverse from Bielsa to Aragnouet, and was found to be a normal biotite-granite of fine or coarse grain, generally quite massive, but here and there, as at Bielsa itself, foliated as though by differential movement when partly consolidated. Its aureole, both in the Géla valley, as described by Bresson, and in the Pinara valley, as observed during our ascent to the Port de Bielsa, evidently belongs to the second of the two types found by Lacroix in the Pyrenees and characterised respectively by hornstones and mica-schist-like rocks.[1] The actual contact was not seen, but at a short distance mica-schists were observed, so closely resembling the Gavarnie schists, at least in outward appearance, that no specimens were collected for comparison. But it was soon found that such rocks extended for a comparatively short distance from the granite, probably less than 400 m., giving place gradually to spotted phyllites, which in turn shaded away into spotted slates. At the Port de Bielsa, at a distance of 800 m. from the granite boundary as mapped by Bresson, the spotting itself had become so slight as to be negligible, and unaltered Palæozoic slates were reached. In fact, it became obvious that a normal aureole had been crossed. Specimens were collected from the intermediate zone of spotted phyllites (191) and from the outer zone of spotted slates (192), which have been microscopically examined by Mr. George Barrow for comparison with the Gavarnie rocks (see p. 423). The above estimate of the width of the aureole agrees with the width in the Géla valley as shown in the Carte Géol. Dét. by Bresson, and does not appear to be exceptionally narrow.

In the Gavarnie and Héas Valleys the igneous and metamorphic rocks have a completely different relationship, being inextricably mingled to form a complex which shows no progressive change in any direction. This fact has long been recognised, and with the exception of a few igneous veins they are coloured as 'granitised' schists and quartzites, gneiss, and mica-schists on the Carte Géol. Dét. The metamorphism in fact is regional; the rocks it has affected, as exposed in the two valleys with their tributaries, are completely altered throughout, i.e. for a length of 11 kilom. and a breadth of 9 kilom. (Fig. 2).

The complex was examined at various places, and the following notes, though referring primarily to the rocks exposed along the torrent which descends the eastern side of the Héas Valley at Héas, may be regarded as descriptive in general of the whole outcrop. The sedimentary rocks vary from mica- to quartz-schists, according as they were originally argillaceous or arenaceous, their banding, which probably represents the original bedding, being now strongly contorted. A specimen (No. 190) of similarly banded schist from the Gavarnie district, showing both quartzose and micaceous parts, is described by Mr. Barrow on p. 422. In that neighbourhood it was noticed that biotite had developed along both the banding and the foliation of some of the schists, and that crystalline limestones were mingled

[1] Lacroix, "Le Granite des Pyrénées et ses Phénomènes de Contact" (2me m'm.): Bull. Carte Géol. Fr., tome xi (1900), No. 71, p. 64.

with them to a slight extent. As seen at Héas gneisses and gneissose pegmatites have been intruded into the schists, and when injected *lit par lit* as in the case of No. 186 (p. 421, from Gavarnie), are often difficult to distinguish from the intervening strips of partly digested sediments on account of the parallel arrangement of their own constituents. When, however, they cross the banding of the schists their igneous origin is obvious; their own foliation is then a continuation of that in the adjacent schist, but is coarse and irregular, being frequently interspersed with 'augen.' A common type is a gneissose biotite-granite, in which the biotite attains a large size (a length of 2½ cms.); less commonly the gneiss contains black schorl along the foliation planes, sometimes as 'augen.'

Both schists and gneisses are seamed by later veins which are distinguished by their unfoliated structure, and are themselves divisible into at least two sets, the one being dark and possibly dioritic, and the other, which in places crosses the former, consisting of white granites and possibly pegmatites. No evidence was obtained of the time-intervals between any of the intrusions, but no chilled margins were observed.

It is obvious, therefore, that there are important differences between the Gavarnie and Bielsa granites. On the one hand, the latter forms a coherent mass or boss of simple outline, almost if not entirely devoid of veins of later granite, and surrounded by an aureole of normal type, in Palæozoic slates, in which the metamorphism, though intense near the contact, diminishes steadily outward and shortly disappears completely; on the other hand, the Gavarnie mass is really a complex in which (1) the commingling of igneous and sedimentary rocks is so intimate that they are frequently difficult to distinguish from one another in the field, and altogether beyond separation on a map; (2) the igneous constituents consist of several granitic injections, including pegmatites, each represented by numerous veins, the later, which are massive, cutting not only the sediments but also the earlier veins, which themselves are foliated; (3) no progressive metamorphism is distinguishable in the sediments, which are, generally at least, represented by crystalline schists and limestones.[1]

These differences are so great as to show that the Gavarnie granite is wholly unconnected with the Bielsa granite. Consequently, as the latter with a probable offshoot accounts for the belt of metamorphosed Palæozoics previously mentioned, there is no reason to regard the proximity of this belt to the Gavarnie granite as other than accidental, and therefore without any bearing on the question of the age of the granite.

The occurrence of chiastolite in the Silurian slates (Fig. 2) thrust over the Cretaceous near Gavarnie is of little importance in view of our ignorance of the original position of the altered rocks and the widespread distribution of Hercynian granites capable of producing them.

Bresson's next statement, however, that the Gavarnie granite encloses not only mica-schists but also masses of unaltered 'schistes' and quartzites, would go far towards proving the Hercynian age

[1] Bresson states that unaltered sediments also are enclosed in the granite.

of that granite. But here I feel compelled to differ from him on a question of fact, for knowing that the age of the schists was said to be Ordovician I carefully examined many exposures in the Gavarnie and Héas Valleys, with the open mind of an enquirer, without discovering any evidence anywhere of unaltered sediments. The shaliest-looking schist (No. 188, p. 422) was found under the microscope to be as thoroughly metamorphosed as any. And in the neighbourhood of the bridge near la Prade de St. Jean, whence Bresson recorded reddish and greenish 'schistes,' almost unaltered, associated with grey quartzites, the whole resembling the Ordovician beds of the Gâla (op. cit., pp. 39, 162, 182), every exposure of sedimentary rock showed, as Mr. Stuart-Menteath pointed out, merely mica- and quartz-schists. In fact, so complete had been the metamorphism in the rocks that were seen that the occurrence close by of comparatively unaltered Ordovician sediments, if unquestionable, would point either to extensive faulting or to the metamorphism of the schists being pre-Ordovician. But it is so far from being unquestionable in view of the inference that palæontological confirmation of the Palæozoic age of any part of the schists is lacking, which may be drawn from Bresson's statement about the *Calymene*, previously quoted, that we may say that no conclusions, one way or the other, should be based on it.

Bresson next points with truth to the close resemblance of the Gavarnie granite to the Caillaouas granite as indicative of a genetic connection, but the post-Devonian age of the second is not so certain. It is based on the occurrence of altered fossiliferous Devonian, at no great distance from the granite, but Bresson's most recent work, published on the Luz sheet, shows that the altered rocks form part of the metamorphosed belt previously mentioned, and are much nearer the granite which crops out at the Pic de Lustou in the middle of the belt than the Caillaouas granite, so that their alteration is, at least, as likely to be due to granite connected with the Bielsa mass, which no one doubts is Hercynian, as to the Caillaouas granite.

Finally, although there is a lack of such direct evidence of powerful pre-Carboniferous earth-movements as is found in connexion with pre-Hercynian granite intrusions in other districts, it is certain that the folding of the Gavarnie schists preceded their thermal metamorphism, and that the latter itself was earlier than at least one period of shearing. This period is attested by the crushing, which in places has reduced the rocks, contact-minerals and all, to mylonite. As it is probably Hercynian from the rarity of later disturbances in these schists, the thermal metamorphism and original folding of the schists may well be pre-Hercynian.

Thus we see that Bresson's evidence that the age of the Gavarnie schists is Palæozoic and their metamorphism Hercynian appears to be inadequate and to leave the question open to solution from other considerations, such as those brought forward in the following pages by Mr. Barrow on petrological grounds. But at the same time light may also be thrown on the problem by stratigraphical evidence, on the lines of a comparative study of the neighbouring granitic and metamorphic rocks. Materials for a preliminary comparison are already to hand in the admirable work of Bresson (pp. 139–197), already so extensively

referred to. There he enumerates six granite-masses as outcropping in the area of the Luz sheet, viz., those found at (1) Cauterets, (2) Néouvielle, (3) Bordères, (4) Gavarnie, (5) Pic du Midi de Bigorre, (6) Conques. To these will be added the Bielsa and Caillaouas granite-masses, the latter already mentioned, because it lies but a short distance to the east of the Luz sheet and has been carefully described by Lacroix.[1]

The first three masses have been shown by Bresson to form a natural group in that they penetrate various Palæozoic formations, including the Carboniferous, and traverse both anticlines and synclines. It is apparent from his descriptions and those of Lacroix[2] that they are coherent and closely resemble one another and also the Bielsa mass in those very features in which the latter differs from the Gavarnie granite, and that, as he maintains, they are Hercynian. Masses (4), (5), and (6) he places in a second group, because they have not reached the Carboniferous and because they form the cores of anticlines. In their case, the accounts make it clear that they are linked closely together and with the Caillaouas granite by the same characters which have been mentioned as separating one of them, the Gavarnie granite, from that of Bielsa, i.e. from the first group. They each consist of a complex of granite, gneiss, and mica-schist like that of Gavarnie already described.[3]

In spite, however, of the marked differences between the two groups, Bresson regards the second also as Hercynian, chiefly on account of the altered character of Palæozoic rocks adjacent to its members. But that it is by no means certain that the latter have produced the alteration, is apparent from his description and that of Lacroix and the subsequent work published on the official map, especially in view of both the frequency of undoubted Hercynian intrusions in the whole area, some of which barely reach the surface, and also the complications arising from the subsequent Tertiary disturbances.

A point of the greatest importance is the fact that these mixtures of schist and granite form the cores of anticlines in those cases where their relations to Palæozoic formations are known, and in two instances are surrounded by comparatively uniform belts of Silurian rocks. But whereas Bresson explains this fact by supposing the granites to be deep-seated 'roots' of intrusions, in my opinion it points strongly to their really being parts of a widespread complex, in age pre-Silurian at least, on which the contiguous rocks have been deposited and which we now see exposed in a few places in large folds by extensive denudation. This view is greatly strengthened by their marked contrast with the Hercynian granites in the neighbourhood, all of which in their turn resemble one another in essentials. The whole question, however, is a large and important one, worthy of close attention and fraught with difficulties on both sides.

[1] Op. cit., pp. 34 et seq.

[2] Op. cit., pp. 45–61.

[3] It is interesting to note that Lacroix draws attention to the fact that in the inner part of the aureole of the Cauterets mass (Hercynian) the felspathised schists remain distinct from the igneous rock injected into them, whereas in the case of the Caillaouas mass they pass insensibly into it through highly micaceous, gneissose granite (pp. 64–5). The second mass thus resembles that of Gavarnie in what is probably a fundamental character.

IV.—Appendix to the Geology of the Gavarnie District and Pyrenean Geology.

By P. W. Stuart-Menteath, A.R.S.M.

MY observations at Gavarnie commenced with the detection of the great fault of the Cirque, sketched in Bull. Soc. Géol. of 1868, and are summarized in my "Pyrenean Geology," pp. 169, Dulau & Co., completed to 1907. The Hippurite limestone having been classed and mapped as typically metamorphosed Cambrian, on the ground that my maps and descriptions are *à priori* inexact, I have recently been concerned with the rectification of the simultaneously asserted Triassic age of the gypseous marls, which I have found to be Tertiary and Cretaceous, from Biarritz to Cardona. Before 1868 the Hippurites of Gavarnie and Heas were already described as anomalous by Leymerie in his Manual and papers, and by Frossard in his "Guide du Géologue." The only specifically determined specimen mentioned by Bresson is from "near the Hourquette d'Alans," a point touching the never-questioned Cretaceous beyond the great fault, and situated at 600 metres above the anomalous sheet in question, as it is figured on Bresson's largest sections. The only fossil of his basal Ordovician I had long previously ascertained to be in a fallen fragment from a peak to the west, outside the rocks in dispute. His 'fundamental section' east of Gedre is a local accident due to a fault, and his section of the Cirque is wildly in contradiction to the real stratification, as well as his section of the Spanish slope of the pass of La Canao and the Hount Sainte. All these errors are corrected on his definitive map of the French Survey, and in the report of the meeting of the Société Géologique in the Pyrenees in 1906. At that meeting the theory founded by M. Carez on the contradiction of my description of Eaux Chaudes, of Bull. Soc. Géol. of 1893, was explicitly acknowledged to be baseless and untenable by that writer himself, as well as by all present.[1]

A course of lectures on the New Geology, delivered by M. Léon Bertrand at the Collége de France, and reported in the "Revue Générale des Sciences" of 29th February, asserts that all geologists are adhering to his tenets as verified in the Pyrenees; and the volume of the Bulletin of the French Survey just published (No. 118) presents nearly 200 pages of gorgeously illustrated compilation to the effect that the interpretation of the Pyrenees proposed by M. Carez and himself is correct, in spite of all observations to the contrary, and especially in spite of the trifling anomalies of Gavarnie and Eaux Chaudes. He explicitly maintains that his first observations at Biarritz are correct, and that he is warranted in extending them

[1] In view of these results, the two papers which I presented at Eaux Chaudes have been suppressed, and I have been refused all rights as a member of the Société Géologique, in spite of a new formal presentation, signed by M. Bresson and M. Fournier, the two survey officers best acquainted with my work. Any novel result of my field observations in the Pyrenees since 1866 will consequently appear dismissible as *à priori* inexact, and any necessary reference to the conditions under which I work will appear to be obviously incredible and deserving of prompt suppression.

to the entire Pyrenees. I have consequently dealt with those observations and their sources in 25 pages of the "Bulletin" of the Biarritz Association, obtainable from Dulau & Co. In the report of M. Bertrand's lectures I find only a reconstruction of a section of Magnan, and in his volume I discover a reconstruction of the 500 sections of M. Roussel. His own additions are what he terms 'coupes perspectives,' to my mind a contradiction in terms, and in my experience the most fruitful source of paradox in geology. Magnan began his work by confounding the Tertiary with the Trias in the Aveyron, and assuming that continuous folds were present where isolated bosses are characteristic. On these convenient errors he added section to section along the entire Pyrenees, and hence finally confounded the Trias with the Tertiary in the Biarritz district. M. Bertrand copied these errors at Biarritz, and has worked back along the whole course of Magnan and his subsequent imitators.

M. Termier, the most expert disciple of the official geology in the Alps, has been called to the rescue, and has already published and elucidated the maps of Biarritz and St. Jean Pied de Port. His conclusion, from the data he is required to justify, is summarized in the Compte Rendu of Soc. Géol. of 2nd December last, and in the text of the maps. He finds that the entire Pyrenees, including all Southern Europe and the north of Africa, consist of rocks shovelled in confusion and reversal from distant and unknown sources. The types of the entire scale of fossils of the south hence demand radical revision. Anomalies in the Paris basin are already referred to mechanical inversion. The scale constructed by William Smith is selected from a comparatively small patch of rocks bordered by the biggest *charriages* described in Suess' latest volume. M. Bertrand states that Suess has informed him that the Pyrenees will be interpreted in his final volume. Since 1883 I have awaited that revision of the scale of fossils which Suess then promised as an essential section of his work. The hints of Neumayr, Walther, and many others have not enabled me to dispense with the *Paléontologie Française*.

It is waste of time to ignore the officially presented aspects of a problem involving the essential structure of the most typical and most accessible of all mountain chains. Alpine geologists habitually quote the abundant literature of the typical Pyrenees. M. Bresson, in applying the Alpine theory to Gavarnie, complains that I had not explained why I referred the facts to illusion. I had found the emergence of the same rocks to the east of Arreau, which M. Bresson has ignored, at fifteen miles to the north of their disappearance on the southern side; and I stated that I was not prepared to believe the entire Pyrenees to be a shovelled mass, as M. Termier has already announced and as M. Bertrand has approximately maintained. For all mining, tunneling, and other industrial work the consequences are of transcendent importance. A theory which destroys the accepted scale of fossils on which its every contention is practically based, suggests hasty mapping rather than a revolution in geology. In presence of the gorgeous maps and sections of the latest volume of the Survey, a practised mining surveyor must remember that his regular proof that a map is worthless is the simple circumstance that paradox is its

outcome. The question for every practical geologist is to find how the error comes in. Is the stratigraphy hastily assumed on fragmentary data? Are the sections only 'coupes perspectives'? Does the rest of the Pyrenees warrant another explanation? Are the Hippurites, with their accompanying forms of a similar fauna, decisive of certain age?

On the last question I may remark that I determined the best specimens of these Hippurites at Miegebat in 1885, and was hence denounced for twenty years, and my Upper Cretaceous figured as Cambrian, along over fifty miles of the official map; whereas fossils that do not touch the problem are eagerly quoted since the wind has changed.

The one point certain regarding the Hippurite limestone is its subordination to that "Austrian Flysch or *Wiener Sandstein*" which I detected in 1881, and which is now accepted as a main element of the Pyrenees. All the fossils of this formation, named and classed in the museums of Austria, Italy, and Switzerland, are repeated in the Pyrenees, and have been of notoriously doubtful value for half a century. Hippurites have been scarcely less puzzling, and have been cited by Darwin in the Jurassic and by most authorities as peculiar to the Turonian. At Eaux Chaudes I have proved the base of the anomalous limestone to be Cenomanian by *Ostrea flabellata*, *Janira quinquecostata*, Sciosia, *Ostrea* cf. *carinata*, and various corals; but its base at Gavarnie is Campanien, on the excellent authority of M. Douvillé. Thousands of years should consequently have elapsed between its deposition at these two points of an identical sheet.

The final and most elaborate sections of M. Bresson are those of Eaux Chaudes, in his description of the meeting of the Société Géologique of 1906. The point most contrasting with my section of the same Bulletin of 1893 is his figure of the Arrioutort, represented as an overlying syncline. Numerous visits to that point have assured me that the Hippurite limestone is there the termination of a long wedge running north and south, and descending almost vertically to the bottom of the neighbouring valleys. As in the single case which I showed Mr. Dixon at La Prade, the limestone figured by M. Bresson as a flat platform is in deep and narrow synclinal wedges descending to beneath the valley bottoms. Such wedges are a special feature of the western Pyrenees, and have the very peculiar property of abruptly changing their direction at right angles. MM. Fournier, Termier, and Bresson all attest this fact in their latest mappings. Its effect is to produce an appearance of underlying Cretaceous exposed by valley erosion. I have traced it to the filling of ancient gulfs or valleys, and hence compared the case to that of Gosau. At Camarasa, and much of Catalonia, the gypseous Oligocene runs vertically downwards to the bottom of such valleys. At Salies du Salat, M. Leon Bertrand has maintained that the Trias has glided along the surface of even the Oligocene, and has moulded itself on an ancient valley to a depth of over 1,300 feet, proved by borings that indicate horizontal bedding. Normal deposition in valleys is less complicated. At Gavarnie and Eaux Chaudes the continual formation of hard travertin filled with transported fossils is a common source of error, and, when submarine and followed by dislocation, involves unsuspected sources of illusion.

M. Lacroix has hence abandoned his first impressions of the early age of ophites, but M. Bresson, in obedience to that abandoned theory, figures as necessarily mechanical intrusions the ophites which at Eaux Chaudes I have traced as visibly volcanic injections. As a regular sheet of Permian, he figures the crush-breccia of a ferruginous lode which cuts across beds of any age. The notion that an unlimited number of worthless arguments amount to one good one, is favoured if verification can be limited to telegraphic phrases.

As regards the age of Pyrenean granite, even M. Bertrand, after founding his earliest example of *charriage* entirely on its assumed antiquity, now admits that it can be Cretaceous or Tertiary, and so follows the example of M. Carez and M. Lacroix, after visiting points I have indicated as decisive. In 1881 I gave the results of microscopic and field examination of sixty ophites, and the notion of their Triassic age has since been generally abandoned, while their intimate connection with the granite is unquestionable. So long as independent observation is classed as *à priori* inexact, the picture of official geology in the recent Traité de Géologie of M. Haug is a true reflection of his present experience rather than of a past which I had occasion to know. Of the theory of its first Director he writes: "By a strange irony of fate, this theory, in spite of all attacks, has remained unshaken: the pretended facts of observation, whose interpretation it professed to furnish, have long since vanished as an illusive mirage . . . It has literally hypnotised several generations of geologists, in virtue of the great scientific authority and especially the high official situation of Elie de Beaumont." Under his successor my most decisive facts have been regularly suppressed in both France and England, because they opposed observation to authority in unavoidable contrast. To accept the existing conditions of verification is to encourage paradox as practically safe. Obvious fallacies of fundamental method can alone secure attention, and resulting confusion in all geology may indicate something seriously wrong.

The description of the entire Pyrenees in the latest volume of the French Survey Bulletin is an avowed extension and justification of its author's first observations at Biarritz. My latest papers, obtainable from Dulau & Co., being a comparison of those statements with the local experience of an engineer, are an unavoidable outrage on high authority. They give the decisive facts concerning Biarritz and Gavarnie. Mr. Dixon naturally refers to them as wholly questionable, and as strangely compromised by references to the dominant theory of Palæontology. They show that every fallacy at Biarritz is supported by the excellent palæontologist M. Douvillé, because those fallacies enable him to evolve a plausible succession of Foraminifera. The innovations of M. Termier and M. Bertrand offer a vastly greater convenience. By their method, evolutionary theories of any fossils can be made plausible against all observations whatsoever. The thirty volumes of Dr. Le Bon's series include one, by a skilled palæontologist, which does for fossils what other writers have done for physics. The Academy of Sciences have noticed in their "Comptes Rendus," but consigned to their archives, two papers which state my results regarding Biarritz and Gavarnie. The theory of Elie de

Beaumont had the fatal defect of offering means of verification. The tunnel of Gardanne has proved that no means of verification can affect the theory of his successors. The engineer commissioned to find coal under the supposed Trias of Biarritz and Cardona, or to tunnel across the supposed Cretaceous basis of the Pyrenees, may find in psychology, but not in the rocks, the justification of the task he undertakes.

The very latest section of Gavarnie is presented in M. Bertrand's book. It represents the overlying Palæozoic in the form of a feeding-bottle, rammed into the heart of the Cretaceous mass that rises from Spain to form the Cirque. It is a caricature of the first erroneous section of M. Bresson, combined with a confusion of Carez, who makes the Cretaceous in question overlie the Palæozoic by 1,500 yards, through mistaking the Port de Pinede for the Port Biel. Bresson's latest section recognizes the fact that the Hippurite limestone forms a vast wedge between the Spanish Cretaceous and the Palæozoic; that it abuts on the great fault which Bertrand is pleased to suppress; and that, far from entering the heart of the Cretaceous, it may probably have left outliers on its summit. Perspective illusion has unfortunately made him sketch the fault as dipping at 23° to the south in place of its real dip of 50°. M. Bertrand similarly sketches a perspective illusion wherever a practical geologist has detected a vertical fault, and by selecting the point of view of his 'coupes perspectives' he obtains any overlap he can wish for. He selects districts never visited by tourists, but Biarritz and Gavarnie have amply illustrated his method. His gratuitous conjectures regarding districts he has never seen are directly contrary to the facts which I have mapped in mining surveys where accuracy is required. They serve the purpose of making local observation intolerable and *à priori* inexact. As Suess reforms the geology of Central Asia, so his emulators deal with the Pyrenees. It is the business of official science to solve all problems at the cheapest rate. The simple suppression of verification will irresistibly appeal to the 'good business head.' The detection of self-contradiction is the only effectual check on the new science, which protects plausible conjectures by defaming every proved expert. The new map and Guide to Interlaken, by Baltzer and his pupils, is a protest against the method applied by M. Douvillé and his subordinates to Biarritz, Interlaken, and Gavarnie. The forcible suppression of my papers is a tribute to the views I share with Baltzer and every local expert from Sicily to the Hartz. The interpretation of the Scotch Highlands proceeds on the assumption that such problems are clearly solved elsewhere. Their excellent description proves them to be as obscure as when Ramsay, in the presence of Nicol, explained them to me forty years ago. The current denial that science bristles with such antinomies has attained a somewhat desperate culmination. But the art of manipulating with the amassed wealth of observation is not proved to be the only legitimate content of human reason, although the entire resources of chromolithography are recklessly squandered in the attempt to exterminate direct research.

V.—Notes on some Rocks from the Gavarnie District of the Pyrenees.

By George Barrow, F.G.S.

(PLATE XIX.)

MR. DIXON has handed me a small collection of rock specimens from Gavarnie (Hautes Pyrénées) and the district to the east. Microscopic sections have been made of these, with the object of ascertaining whether the structures and composition of the rocks throw any light on the vexed question of the age of the metamorphism in the two areas specially dealt with in the preceding communication.

The igneous rocks from Gavarnie and Héas, both in their general character and mode of occurrence, show the features specially characteristic of very old intrusions. They tend to infinite subdivision, occurring either as thin sills of granite or as veins of more or less foliated pegmatite (giant granite). It is an additional feature of these thin intrusions that in the majority of cases their foliation is of protoclastic (pre-consolidation) and not of kataclastic (post-consolidation) age.

The two specimens, 186 (near Gavarnie) and 189 (Héas Valley, near the cirque de Troumouse), are typical examples of a sill of granite and a foliated (protoclastic) pegmatite. The first (186) is mainly a typical igneous 'granulite,' in which the grains are of fairly uniform size, and there are no specially large patches of either quartz or felspar, though the junctions of the component grains are essentially the same as those of a normal granite. It is composed of quartz, orthoclase and plagioclase, with a subordinate amount of brown and white mica. The plagioclase is mainly oligoclase, and shows a typical feature of these old rocks, namely, the development within the plagioclase crystals of numerous small flakes of white mica, due probably to their being kept at a high temperature for a long period after they had separated out. The biotite is in irregular shaped patches and often intergrown with muscovite, only a small quantity of the latter being free.

On the margin of the igneous granulite are films or patches rich in felted brown mica, having the reddish-brown tint of the 'contact mica,' developed in altered sediments by heating. They show clearly the presence of original films of sedimentary material, now intensely altered; the bulk of the new quartz and felspar associated with the mica-films merges absolutely into the adjacent igneous material, and no trace of a true junction between the two is visible in the microscopic section. This absence of clear junctions is a characteristic feature of *lit par lit* intrusion in very old rocks.

In the gneissose pegmatite 189, large crystals were formed, which are now more or less rounded, as well as surrounded by a mixture of fine 'granulite' material and slightly larger grains. The latter adhere so closely to the large rounded crystals as to suggest they were broken off from the latter during 'pasty-flow,' the structure being, in fact, a typical 'protoclastic foliation.'

Three specimens of the older altered sediments have been selected for examination. Of these the first, 187 (near Gavarnie), is a hard,

tough, crystalline rock showing marked contortion, which had clearly been subjected to great mechanical stresses and deformations before heating. These stresses broke up the original sediment into lenticles or phacoids, the length of which suggests the rock was a gritty shale, possibly a banded shale.

The lenticles are built up of well-crystallized quartz and felspar, the whole thickness of a single lenticle being often filled by one grain of quartz. There are also present patches of irregular-shaped garnet, often bordered by brown mica. These lenticles are separated by films or flaser-ribands of pale fibrous material suggestive of decomposed sillimanite. In this only a few needles of sillimanite can be still recognized; but where the fine mesh comes into contact with quartz the terminal threads of the former penetrate the quartz, and in this case are at once seen to be sillimanite, which has been protected from decomposition by its coating of quartz. This latter phenomenon is a very characteristic feature of these flaser films of sillimanite. The rock is a sillimanite gneiss.

The second (188), also from Gavarnie, is a slightly horny-looking, brownish rock, largely built up of lenticles and films rich in brown mica. The lenticles are of slightly different composition; one set are largely composed of rich red biotite (contact-biotite) associated with a little sillimanite; the other set are composed of sillimanite in long-bladed crystals arranged parallel to the foliation, and associated with brown mica in somewhat smaller crystals. Both types of lenticles are enveloped by films of fibrous sillimanite, much decomposed, and practically identical with those in the rock last described. The rock is a sillimanite gneiss, and was clearly a shale originally and markedly less siliceous than 187.

So far as the minerals are concerned, these rocks might be of almost any age; but experience has shown that if of post-Torridon age the sillimanite-bearing rocks would be restricted to the immediate margin of a large mass of coherent granite, a fact well brought out by Dr. Barrois in his descriptions of the great coherent masses of granite in Brittany, which are substantially of the same age as the great coherent masses referred to by Mr. Dixon.

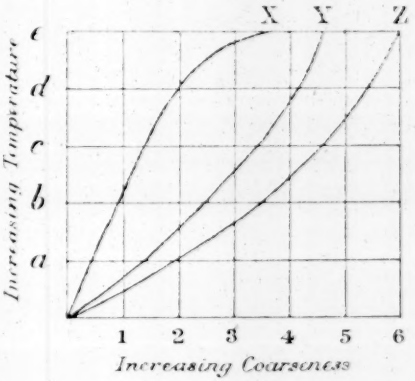
The third type (190, from the east side of the Pau Valley at Gavarnie) was much more siliceous originally and probably a banded very fine sandstone, partly calcareous. It is a banded rock, with a fine gneissose structure, the darker bands being composed of greenish-brown hornblende in irregular-shaped patches, disseminated through a groundmass of plagioclase felspar with which a subordinate amount of quartz is associated. The hornblende suggests the original rock was slightly calcareous. The lighter-coloured bands are more quartzose and there is little or no hornblende present; but decomposed biotite is fairly abundant. The structure of both is essentially that of a 'granulite' produced by the prolonged and intense heating of a somewhat crushed siliceous sediment. In many respects the lighter bands bear a close resemblance to the less common 'plagioclase phases' of the Moine gneiss. (See Photo, Pl. XIX, Fig. 1.)

Of the rocks occurring within the aureole of contact metamorphism surrounding the large coherent granite of Bielsa, two may be referred

to. The first (191), collected about half-way between the River Pinara and Port du Bielsa, is a very fine spotted schist or phyllite. Like the specimens from the older series already described, this was subjected to considerable deformation before heating, and is now a very fine schist largely composed of quartz grains and small crystals of white and brown mica. In this, as a matrix, are set a number of large patches of shimmer aggregate material, almost certainly decomposed andalusite. (Photo, Pl. XIX, Fig. 2.)

The second (192), from Port de Bielsa, is a fine phyllite composed of small flakes of biotite, with some muscovite and chlorite, wrapping round lenticles of quartz and chlorite. The latter are reconstructed segregations, formed when the rock was crushed, anterior to the heating. The fine texture of these rocks (190 and 191) at once separates them from the former group; in the Archæan rocks it would be practically impossible to find such large patches of andalusite associated with such a fine groundmass.

Rocks of very fine texture and well foliated do occur on the 'outer margins of crystallization' of the old Archæan areas, but they contain no such minerals as andalusite. It is necessary to go some distance into these areas, in the direction of increasing crystallization, before such minerals are met with, and by this time the texture of the groundmass has invariably become far coarser than that of 191.



The lines X, Y, Z show the coarseness of the texture for a given temperature in—

X [1] = post-Torridon aureoles of thermo-metamorphism.
Y = areas of newer Archæan ,, ,,
Z = areas of older Archæan ,, ,,

The distinctive feature of the two groups is best shown by the size of grain of the quartz-felspar material in the two specimens 190 and 191, which is brought out by the photographs of sections of them (Pl. XIX, Figs. 1 and 2). The texture seen in Fig. 1 may occasionally be met with close to the actual margin of a great coherent mass of

[1] The flattened termination of X is intended to show the rapid increase of texture just at the margin of a big intrusion.

post-Torridon granite, but it is invariably restricted to within a few feet of that margin; in the older Archæan areas it may cover many hundreds of square miles without a break; it is regional. The mode of occurrence of the rocks in the Gavarnie and Héas Valleys, described by Mr. Dixon, is characteristic of the regional or Archæan type of thermo-metamorphism.

In both types of areas, as we approach the zones of increasing metamorphism, a series of minerals is met with which requires an increasing temperature for their development. The Archæan areas of thermo-metamorphism can be broadly distinguished from those due to post-Torridon intrusions by the far more rapid increase in coarseness of texture of the groundmass of the former, *if well foliated*. The difference may be illustrated diagrammatically by arranging a series of vertical and horizontal co-ordinates. In the diagram (p. 423) the minerals *a*, *b*, *c*, *d*, etc., represent increasing temperature, while 1, 2, 3, 4, etc., represent increasing coarseness of texture. The lines X, Y, Z show the difference in texture produced by the older and newer thermal metamorphism.

EXPLANATION OF PLATE XIX.

Fig. 1 (No. 190).—Rock-section taken from the east side of the Pau Valley at Gavarnie (see text for fuller details).

Fig. 2 (No. 191).—Rock-section from half-way between the River Pinara and Pont de Bielsa; a very fine spotted schist or phyllite.

The two photographs show the difference in size of grain of the quartz-felspar material in (1) the older Archæan rocks, and (2) in any post-Torridonian rocks; the crystalline metamorphism being due in both cases to thermal action.

VI.—The Waterberg Sandstone.

By Professor E. H. L. Schwarz, A.R.C.S., F.G.S. (Rhodes University College, Grahamstown, South Africa).

THE geology of South Africa is once again being brought to the notice of European geologists in the able papers by Dr. Voit in the *Zeitschrift für praktische Geologie*. In the first instalment Dr. Voit follows Drs. Hatch & Corstorphine[1] in correlating the Waterberg Sandstone with the Table Mountain Sandstone, which is a small matter perhaps, but as it would in Europe be equivalent to correlating the Old Red Sandstone with the Torridon Sandstone, it is necessary to state the objections to this correlation and enable geologists to judge for themselves whether it is right or wrong.

To emphasize the difference between the South African older and younger rocks, which are separated by a great unconformity, and the younger series of which begins in the Palæozoic with the top of the Silurian or base of the Devonian, I have used the words Palæo- or Pal-Afric and Neo-Afric as group names. The Table Mountain Sandstone is at the base of the Neo-Afric group, and the Waterberg Sandstone at the top of the Pal-Afric; the former is a blue, false-bedded sandstone weathering grey, and the latter consists of a series of conglomerates and sandstones characteristically coloured red or buff.

[1] "Geology of South Africa" (London, 1905), p. 179.

No. 190.

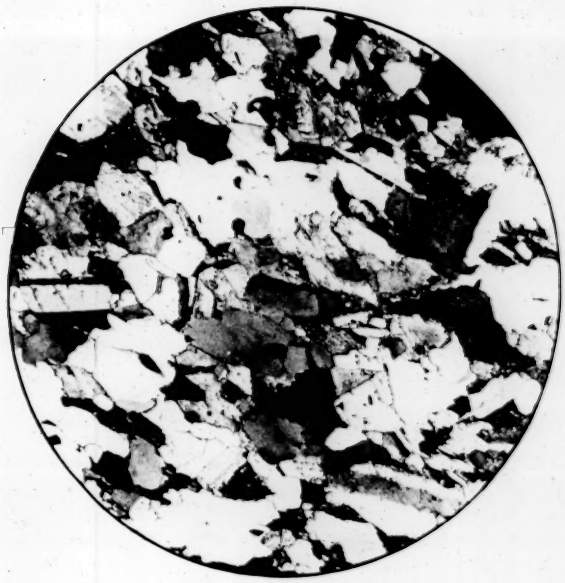


Fig. 1.

No. 191.

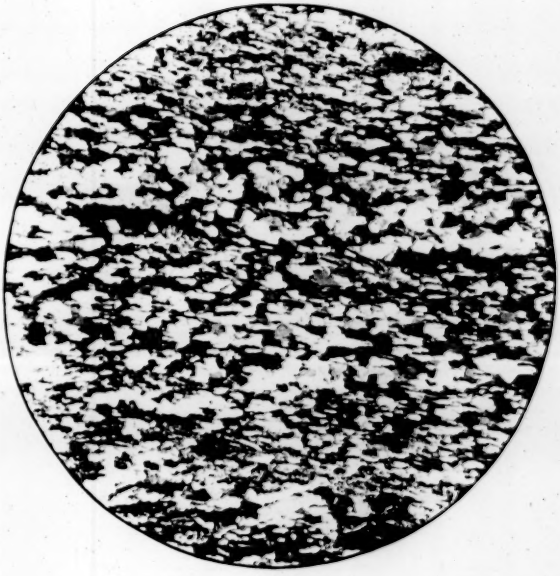


Fig. 2.

Rock-sections from the Gavarnie District of the Pyrenees.

The Table Mountain Sandstone surrounds the sub-continent on the west and south, and is usually marked in on the east as well, but in Natal Mr. Anderson at first refused to consider the sandstones as equivalent to the Table Mountain Sandstones, calling them instead Palæozoic Sandstones. The only place I have seen the Natal Sandstone was near Pinetown, where the rock is a red arkose.

On the west the Table Mountain Sandstone is typically developed on the mainland opposite the Cape Peninsula, where it is some 5,000 feet thick; proceeding northwards the sandstones thin out, and gradually the overlying beds, the Bokkeveld (Devonian) and Witteberg Beds, disappear from beneath the Dwyka (glacial) Conglomerate, so that the last rests on the thinned-out Table Mountain Sandstone; finally at Stinkfontein Poort, north of Van Rhyn's Dorp, the Table Mountain Sandstone itself wedges out. We can to a certain extent examine the rocks below the Karroo by means of volcanic pipes, which act as boreholes, bringing the rocks to the surface, and we know from the ejectamenta of the Sutherland volcanic pipes that the Table Mountain Sandstone must underlie the Karroo in this part of the country, so that in drawing a section through the middle of South Africa we cannot be far wrong in filling in the sub-structure on the lines indicated in the upturned edges of the basin in the west.

M. Malmesbury } Pal-Atric Beds. T.M.S. Table Mountain; B. Bokkeveld; W. Witteberg; D. Dwyka; K. Karroo, with intrusive Dolerite.
X. Matsap }

Sketch Section through the middle of South Africa from the south to just beyond the Orange River on the north, to show the relationship between the Dwyka Conglomerate and the Table Mountain Sandstone on the one hand, and the Dwyka Conglomerate and the Matsap (Waterberg) Sandstone on the other.

A short way to the north of the Stinkfontein Poort there is a series of remarkable arkoses and grits which Dr. Rogers named the Nieuwerust Beds,[1] which undoubtedly lie unconformably below the Table Mountain Sandstone, and which, therefore, belong to the Pal-Afric group. Further to the north, in Namaqualand, there has been marked on the older geological maps of South Africa a patch of Table Mountain Sandstone. I can give the authority for this from the original notes made on the spot by the late Dr. W. G. Atherstone in 1854: "Schaap River. Granite forms the base of the mountain, gneiss above it, and, covering all, the Table Mountain quartzite. (The latter is) externally of a red colour, and breaks off in vertical cliffs, but (with) apparently horizontal beds precisely like Table Mountain." I think there can be little doubt that this Schaap River Sandstone belongs to the Nieuwerust Beds; certainly it is different

[1] Ninth Annual Rept. Geol. Comm. (Cape Town, 1905), p. 55.

from the Table Mountain Sandstone. If Drs. Hatch & Corstorphine are right in correlating the Waterberg Sandstone with the Natal Palæozoic Sandstone, then it seems likely that these Nieuwerust Beds may turn out to be the western equivalents of the Waterberg Series.

In Prieska we have red sandstones which Stow called the Matsap Beds, and which are undoubtedly the equivalents of the Waterberg Sandstone; all geologists are agreed on this. The Dwyka Conglomerate rests on the upturned edges of the Matsap Beds, and it also rests on the eroded edges of the Table Mountain Sandstone of the south; therefore Drs. Hatch & Corstorphine and Dr. Voit say they must be equivalent. But the Dwyka Conglomerate in the south rests on beds of Table Mountain Sandstone which had been very little disturbed, and the two epochs left out in the unconformity, the Bokkeveld and Witteberg, are of no very great geological extent. On the other hand, the Matsap Beds were buried and metamorphosed, were exposed again by denudation, thrust up into high mountain ranges, and cut into peak and valley before the Dwyka Conglomerate was laid down. The glacial boulder-clay is in Prieska extraordinarily fresh and unaltered, and rests in the valleys cut in the Matsap Hills as if the Ice Age during which it was formed was but a short time past, and we can find in the till boulders of Matsap Sandstone altered and metamorphosed, thus proving the vast lapse of time which must have intervened between the laying down of the Matsap sediments and the Dwyka Conglomerate.

The Waterberg (Matsap) Sandstone, then, is a series of rocks with a prevalent reddish or buff colour like the Torridon Sandstone, the Table Mountain Sandstone a blue quartzite weathering grey. The Dwyka Conglomerate rests on the Table Mountain Sandstone with an unconformity represented elsewhere by a conformable series of beds (Bokkeveld and Witteberg) 4,000 feet thick; it rests on the Waterberg Sandstone with an unconformity representing a lapse of time during which the Waterberg Sandstone was buried, metamorphosed, folded into mountain chains, and denuded. Judged by European standards, the Table Mountain Sandstone–Dwyka unconformity would mean the leaving out of the Devonian and Carboniferous epochs, quite time enough many would say for the changes to have gone on in the Matsap (Waterberg) Beds, but where the series is conformable there was a steady process of sedimentation from Table Mountain Sandstone times to the Dwyka, whereas between the Matsap Beds and the Dwyka there was sedimentation certainly equivalent in extent to the Bokkeveld and Witteberg epochs, in order to procure 'cover' for the folding to take place, then the period of crushing, and finally a prolonged land period ending in the Permian Ice Age, and this lapse of time to my mind must have been immeasurably longer than the other, so much so that I still think the Waterberg (Matsap) Beds should be put into the Pal-Afric group. If the Nieuwerust Beds turn out to be the equivalents of the Waterberg Sandstone, the question will be settled definitely, for the outcrops of the two rock-systems are close enough in Bushmanland to enable one to make sure that there is a great unconformity between them.

NOTICES OF MEMOIRS.

I.—Index Generum et Specierum Animalium.

Report of a Committee consisting of Dr. Henry Woodward (Chairman), Dr. F. A. Bather (Secretary), Dr. P. L. Sclater, Rev. T. R. R. Stebbing, Dr. W. E. Hoyle, Hon. Walter Rothschild, and Lord Walsingham.[1]

STEADY progress has been made with the indexing of the literature for the second portion of this Index (1801–1850). Among numerous works dealt with, the compiler, Mr. C. Davies Sherborn, specially mentions the following:—

Boisduval's works on Lepidoptera.
Publications of the Bologna Academy.
Bonaparte's numerous tracts and his "Conspectus Generum Avium."
Publications of the Bonn Natural History Society.
Publications of the Bordeaux Linnean Society.
Roret's edition of the "Suites à Buffon."

The number of index slips increases with great rapidity, and continual effort is needed to keep this mass of material in order for reference. The sheets already arranged constitute a mine of information for monographers and others. They are preserved in the Geological Department of the British Museum (Natural History), where reference is frequently made to them by members of the staff and outside workers, while information derived from them is often asked for by correspondents at a distance. The Committee would, however, be glad to see still more advantage taken of the facilities now offered for the consultation of this valuable aid to systematic work.

A copy of the first volume of the "Index" is being shown in the Science Hall of the Franco-British Exhibition.

The Committee asks for reappointment, and earnestly hopes that the full sum of £100 will be granted towards the continued preparation of the "Index Animalium."

II.—Glacial Drift in Scilly.

OUR attention has been drawn by Mr. W. A. E. Ussher to the following passage in a paper by the late E. A. Wünsch, "On Raised Beaches," read on June 15th, 1894, at the Joint Meeting of the Scientific Societies of Cornwall at Penzance. In that paper he accepts the evidence put forward as to the stranding of erratics on the shores during the formation of the raised beaches, and continues thus:—"We must hence refer the age of our Raised Beaches to the later stages of the Glacial Period, and with this great northern drift with its heavier burden checked by and deposited in front of the Isle of Wight and Portland Bay we must connect the effects of the same drift farther westwards, by means of which, and by ground ice and

[1] Submitted to the Meeting of the British Association, Section D, Zoology: Dublin, September, 1908.

local ice-floes, the dispersion and extensive distribution of flint so conspicuous in all southern beaches, and extending even as far as the Scilly Isles, can alone be accounted for."

III.—On the Viscosity of Ice. (Abstract.) By R. M. Deeley, F.G.S.[1]

THE movement of glaciers has excited a great deal of interest, and the facts recorded concerning their motion have shown that the flow is such as would result if ice obeyed the laws of viscous flow. The viscosity of a liquid is measured by the tangential force per unit area of either of two horizontal planes at unit distance apart, one of which is fixed, while the other moves with unit velocity, the space between the planes being filled with the viscous substance. Taking such figures as are available, and estimating others as nearly as may be, it is possible to calculate roughly the viscosity of several glaciers. Stated in dynes per square centimetre by 10^{12}, the results obtained are roughly as follows:—The Mer de Glace 27, Morteratsch 143, Lower Grindelwald 3, and Great Aletsch 126. It seems probable that these discrepancies arise rather from differences in the actual viscosity of the glacier ice, due to its varying granular structure, than to errors in the data. Further measurements are required, however, before this can be regarded as proved.

It is also shown that the viscous motion of a glacier such as the Great Aletsch must exercise a drag on the floor upon which it rests amounting to two and a half tons per square foot, and that owing to the ability of the ice to transmit thrust, this force may be greatly exceeded at points where much resistance to motion is caused by inequalities in the floor upon which the ice rests.

McConnel made a number of very careful experiments on the shearing motion which can be produced by even very small forces in directions at right angles to the optic axes of ice crystals. A careful consideration of the experimental data shows that the rate at which the motion is produced is proportional, very nearly, to the stress, and that the resistance to shear increases very rapidly with rise of temperature. The flow at right angles to the optic axis is such as would be the case if ice were viscous (liquid) in a direction at right angles to the optic axis, the viscosity at 0° C. being about 3×10^{12} dynes per square centimetre.

McConnel showed that when the load was taken off a bar of ice which had been yielding viscously, there was a slow partial recovery of the original form. Experiments with highly brittle pitch also showed that when the load was taken off a weighted bar there was an immediate elastic recovery, and also an additional slow recovery. When this slow recovery ceased, the pitch bar again began to bend under its own weight.

[1] Royal Society, June 4th, 1908. Communicated by Dr. H. Woodward, F.R.S.

REVIEWS.

RADIOLARIA FROM TRIASSIC AND OTHER ROCKS OF THE DUTCH EAST INDIAN ARCHIPELAGO. By Dr. GEORGE J. HINDE, F.R.S. pp. 44, with 6 plates. [From Dr. Rogier D. M. Verbeek's "Report on the Geology of the Moluccas": Jarb. v. h. Mijnwezen in Nederlandsch Oost-Indië, vol. xxxvii (1908).]

THE rocks containing the Radiolaria described in this memoir were obtained, some years since, by Dr. R. D. M. Verbeek from the islands of Timor, Roté (Rotti), Savu, Ceram, Celebes, Buru, and Mangoli. These Radiolarian rocks are very similar in character to those already known from other countries. The greater number are of chert or hornstone, either light grey, reddish, or jaspery, apparently entirely siliceous, and, as seen in microscopic sections, filled with Radiolaria, now, for the most part, in the condition of casts, showing merely the outlines of the organisms. In other cases the rock is siliceo-calcareous, the Radiolaria in these retaining their siliceous character and occasionally their structural details. Radiolaria are also present in other rocks, mainly, if not entirely, composed of limestone, and containing large numbers of *Halobia*, but in these, as a rule, the Radiolaria are very imperfectly preserved and, for the most part, replaced by calcite. Exceptionally, however, some of the tests remain siliceous, with their outlines clearly defined, although their interior structures have disappeared.

Geological Age.—The association of the Radiolarian rocks in Roté and Savu with beds of limestone filled with the shells of characteristic Molluscan genera, *Halobia* (Bronn) and *Daonella* (Mojsisovics), and in one locality in Savu with the Belemnite genus *Asteroconites* (Teller), is satisfactory evidence that the rocks in question belong to the horizon of the Upper Trias. If this conclusion is confirmed, an additional importance will be attached to the Radiolaria from the rocks of these islands as representing forms characteristic of this geological period. Fortunately, many of the Radiolaria in these Upper Triassic beds on Roté and Savu are fairly well preserved, and most of the forms described and figured in the paper have been obtained from them.

With regard to the geological age of the boulders and pebbles of Radiolarian rocks occurring in secondary positions on the islands of Ceram, Mangoli, Buru, and Celebes, very little is known at present. The rocks from Ceram are considered by Dr. Wanner to be probably Triassic, and a similar age is assigned to those from East Celebes. Those from Buru and Mangoli are considered to be younger, probably Jurassic or Lower Cretaceous, but they are of less importance, as the Radiolaria in them are too poorly preserved for specific identification. Detailed descriptions follow of the position and general characters of the Radiolarian rocks from different localities, with a list of the genera recognised in them. To this is added a description of the genera and species, illustrated in the six large octavo plates. A summary

shows that the Radiolaria examined belong to five orders, referable to 28 genera and 83 species, viz.—

Name of Order.	No. of genera.	No. of species.
Beloidea	1	1
Sphæroidea	5	10
Prunoidea	2	3
Discoidea	4	9
Cyrtoidea	16	60
	28	83

Of the 83 species described 74 are new, and not more than 9 are known already from other areas. A significant feature is the large proportion of species, nearly three-fourths of the whole, belonging to the Cyrtoidea.

The Radiolarian rocks *in situ* on the islands of Roté and Savu have yielded the greater number of the species described. From Roté 41 species were recognised altogether; 35 of these are not known elsewhere, and 6 are common to other localities. Most of these forms are from cherty or mainly siliceous rocks, but in the *Halobia* limestone of Baä 10 species of Cyrtoidea were met with, which appear to be restricted to this rock and locality. From Savu 33 species are described, 24 of which are limited to this island and 9 occur in other islands.

From the rolled and travelled cherty fragments from Ceram 10 species of Radiolaria were found, only 20 of which belong exclusively to that island, and 8 are common to other islands. Also in Celebes, out of 13 species found in pebbles of chert, 8 have not been met with elsewhere, whilst 5 occur in other areas. The number of species in these detached pieces of rocks, which are also present in the Radiolarian deposits of Roté and Savu, gives support to the view that the original rocks on Ceram and Celebes, from which they were derived, are of the same Triassic age as those of Roté and Savu. Only one species of Radiolaria was recognised in the *Halobia* limestone of Timor, whilst those of Baru are so badly preserved that no species could be determined. No Radiolaria were met with in Mangoli.

The 44 pages of descriptive letterpress, accompanied by 6 plates, comprising 80 well-executed figures of the species determined from these East Indian Islands, makes another valuable contribution by Dr. G. J. Hinde to our knowledge of the fossil Radiolarian fauna of the Dutch East Indies, the geology of which has been so ably investigated by Dr. Verbeek and later by Dr. G. A. F. Molengraaff, to which also earlier contributions, in various branches of Palæozoology, will be found in the past volumes of the Geological Magazine.[1]

[1] R. D. Verbeek, "The Geology of Central Sumatra": Geol. Mag., 1875, pp. 477–86; 1877, p. 443; 1880, p. 286. H. B. Brady: "Fossil Foraminifera from the West-Coast District, Sumatra," 1875, pp. 532–9, Pls. XIII and XIV. Dr. A. Günther: "Fish Fauna of the Tertiary Deposits of Sumatra," 1876, pp. 433–40, Pls. XV–XIX. Henry Woodward: "Fossil Shells, Corals, etc., Sumatra," 1879, pp. 385, 441, 492, 535, Pls. X–XV. Dr. G. A. F. Molengraaff: "Geol. Expl. Central Borneo, 1893–94" (Review): Geol. Mag., 1903, pp. 167–76, and Appendix by Dr. G. J. Hinde, "Fossil Radiolaria of Central Borneo," 1903, pp. 172, 173.

CORRESPONDENCE.

COCCOSTEUS MINOR, HUGH MILLER, IN THE OLD RED SANDSTONE OF DALCROSS, INVERNESS-SHIRE.

SIR,—Whilst collecting from the Old Red Sandstone of the Hillhead Quarry, near Dalcross in Inverness-shire, Mr. Wm. Taylor, of Lhanbryde, and myself found large numbers of remains of *Coccosteus minor*, H. Miller. The quarry has yielded previously only *Homosteus Milleri*, Traq., and Osteolepid scales.

Coccosteus minor and *Homosteus Milleri* have not yet been found elsewhere in the Moray Firth area, but are fairly abundant at Thurso.

It thus seems probable that the Hillhead Quarry represents a different horizon to that of the ordinary nodules of Cromarty, Lethen Bar, and Tynet Burn.

D. M. S. WATSON.

THE GEOLOGICAL DEPARTMENT,
THE UNIVERSITY OF MANCHESTER.

MESSRS. CRAWSHAY AND WORTH ON THE SUBMARINE GEOLOGY OF THE ENGLISH CHANNEL.

SIR,—I have read with much pleasure Professor Cole's appreciative reference to the papers by Messrs. Crawshay and Worth on the "Submarine Geology of the English Channel," as I feared that a geological paper published through the enterprise of a Biological Association might escape the notice of geologists. By the kindness of Mr. Worth I have been kept posted up in the progress of the great work that the Marine Biological Association has been doing. In the subject-matter of the aforesaid inquiry, physics, zoology, and geology are equally concerned, with the natural result that no physical, zoological, or geological society can be expected to afford the space to discuss it. No one could have ventured to hope that a Biological Association would have dealt with the "Rock Remains in the Bed of the English Channel" and the "Geology of the English Channel,"[1] more especially as neither of these subjects can directly interest pure biologists!

Readers of the GEOLOGICAL MAGAZINE have, no doubt, been much amused at my own efforts in this matter. By the year 1889 I had brought the subject before the British Association at Swansea, Southampton, York, Southport, and Birmingham; published seven papers in the Transactions of the Devon Association, one each in the Proceedings of the Royal Society, in the Journal of the Linnean Society, and in the Proceedings of the Royal Dublin Society; had made two tentative approaches to the Geological Society, with assaults on the GEOLOGICAL MAGAZINE and *Nature* unnumbered!

One of the most important problems in this inquiry is the way in which the bed of the English Channel has been kept free from the deposition of sediment. A paper on deposition and denudation, at Birmingham, in 1886, was with difficulty got on the list for reading. I printed it privately, and, though not published, it has within the present year been cited in an engineering book as an authority!

[1] Journal of the Marine Biological Association, vol. viii, No. 2, May, 1908.